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THE PROPER COMPENSATION FOR RAILROAD CURVES.

By WILLIAM R. MORLEY, M. Am. Soc. C. E.
READ APRIL 18TH, 1883.

WITH DISCUSSION.

My attention was first called to the subject of the proper compensation for curves on the location of the Veta Pass line—3 feet gauge—in 1876, where it was necessary to use a maximum grade of 4 per cent. and a maximum curvature of 30 degrees of angular deflection per hundred feet (radius, 193$\frac{2}{10}$ feet). A study of the authority on the subject, which at that time, if I recollect, was Vose's Manual, led us to adhere to the sliding scale, making the compensation proportional to the radius of the

NOTE BY THE SECRETARY.—This paper presents the author's opinions as communicated by him to Mr. A. A. Robinson, M. Am. Soc. C. E., in a letter which Mr. Robinson has transmitted to the Society. Mr. Morley was preparing to present his views directly to the Society, but was accidentally shot on January 3d, 1883, while on a reconnaissance for the Mexican Central Railway, of which he was the Chief Engineer.

There is appended a copy of instructions to engineers on the location of the Sonora Railway, prepared by Mr. Morley.

curve. We began compensation after 10 degree (radius, 573$\frac{7}{10}$ feet) curves, or, in other words, nothing under 11 degree curves were compensated. For 11 degree (radius, 521$\frac{7}{10}$ feet) curves we allowed at the rate of 0.05 per degree, and increased this allowance until at 30 (radius, 193$\frac{2}{10}$ feet) degrees the grades were level. In other words, we used up the 4 per cent. grade in 20 degrees of curvature, beginning at 11 degrees. After the track was laid it became the plainest possible fact that the compensation was too much, and the higher we got in curvature the more evident it became. The difference, however, between an uncompensated 10 degree and a compensated 11 or 12 degree curve was so small that I was led to think that the compensation used there might not be far out of the way. Acting on this and such other information as we were able to collect, we adopted the 0.05 standard on all the surveys of 1877 and 1878 on the Atchison extension, and the location from La Junta to Raton was made on this basis. On the road constructed on this section we had grades as follows, if I am not mistaken: La Junta to Trinidad, maximum 1.2 feet to the hundred; from Trinidad to Morley, 2 feet to the hundred; Morley to the summit, 3.50 feet to the hundred, south bound; from Raton to the summit, 3.3 feet to the hundred, and from Trinidad to La Junta, 0.6 feet to the hundred, making in all five different rates of maximum or ruling grade, varying from about 30 feet to 185 feet per mile, all located at the rate of .05 compensation per degree of curvature, regardless of radius, up to our maximum of 10 degree curves. In addition to this, was also the switch back over the Raton tunnel, located on a maximum grade of 6 feet to the hundred, and of 16 degree (radius, 359$\frac{3}{10}$ feet) curves, with the same rate of compensation. When it came to operation, we discovered the following facts: That on the 0.6 *per cent.* maximum grades the compensation was about right, or, if anything, a trifle too small. On the 1.2 *per cent.* grades there was a very perceptible "picking up" in the movement of the train, when the engine was fully loaded, as it struck a curve. On the other sections this picking up became more and more perceptible as the maximum increased, so much so that on the higher grades it was possible to shut off some steam and still keep up the motion as the train rounded the curves. The higher the degree of curvature the more this "picking up" was noticeable, which seemed to me convincing proof that the compensation for the higher grades was too much, while for the low, 30 feet per hundred, it was about right. Reasoning from this and from my previous experiences in the Veta Pass, we came

to the conclusion that the adopted theory, that the resistance to the curvature was in some proportion to the radius, was wrong, in the main, if not almost wholly, and we then adopted for future location what might be termed a sliding scale, increasing not with the radius, but with the decrease in ruling grade.

The figures which we then adopted for convenience in location were:

Rate of maximum grade,	.0 to 0.7 ft. per hundred;	compensation	0.06 per 100 ft. per degree.
" " " "	0.7 to 1.4 " "	" "	0.05 " " " " "
" " " "	1.4 to 2.0 " "	" "	0.04 " " " " "

And since that time we have located and constructed from 1 200 to 1 500 miles of road on various maximum grades from 0.3 up to 3 per cent., and I have taken a great deal of pains whenever opportunity offered to ascertain whether or not this compensation was about correct. During the last three years on the Sonora road I have tested it as carefully as possible on different maximum grades, as follows: 0.4 per hundred feet, 0.5 per hundred, 1.0 per hundred, 1.2 per hundred, 2.0 per hundred and 2.4 per hundred; and I found in every case that not only did the train movement not "pick up" on striking the curves, but that whenever, as was seldom the case, there was any perceptible drag of the train in rounding the curves, an examination showed that something was wrong with the track. In one instance notably, on a 2.4 *per cent.* grade on a 10 degree (radius, 573$\frac{7}{10}$ feet) curve, the locomotive engineers frequently stuck. A careful instrumental examination showed two facts: First, the outside rail was the lowest; and second, the gauge had not been widened on the curve. With these rectified, no further complaint was heard, and whenever afterward complaint was made of any curve, it was found to be the fault of the track, and not of the compensation.

From these facts I have come to the conclusion that the resistance due to curvature is measured not by the length of radius, but by the length of train, or, what is the same, by the ruling grade. I think, however, that there is another element which has much to do with this. It is my belief that while there may be and probably is some increased resistance due to radius, this is largely overcome by the elevation of the outer rail, and especially by the widening of the gauge, and that really what we have to figure on in compensation is almost exclusively length of train alone. I believe that my rules for widening of gauge and eleva-

tion of outer rail are about the same as yours. Mine are half an inch of elevation per degree of curve, the outer rail being elevated and the inner depressed each one-half. In widening the gauge I have allowed $\frac{1}{16}$ of an inch per degree of curvature. It is probable that the scale we have adopted of .06, .05 and .04, each over a considerable range of maximum grade is not absolutely correct, and that it should be subdivided into thousandths for small fractions of grade, as, for example, perhaps, $\frac{55}{1000}$ might be more absolutely correct for a 1 per cent. grade than .05. But to run this question into thousandths would make it rather too much detailed for practical use. I am satisfied, however, that the figures stated are sufficient compensation for the grades in the range allowed to each; that is to say, considering the average train, which is supposed to be loaded, and with a single engine. If it were a rule to run double-headers, and thereby double the length of the train, our compensation is not sufficient. This is a matter I have also tested in a number of instances, and it would not, in my opinion, be justifiable to use up elevation which is required to be gained, by compensating for double length trains, except in places where they will be used frequently.

According to my notion, a road should be located for what it is expected to do, and unless it is proposed to run double-headers as a business, the compensation should be made for single-headers, and for this our figures are sufficient. It would not be difficult to determine approximately what would be required where double-headers are expected. In the two or three instances of this kind that I have had, I used the same compensation for the heavy grade with two engines that I would have used on the lighter grade where one engine would have the same number of cars, and this seems to be all that is required. For example, the section of the Sonora road from Imuris to Agua Zarca, 1 *per cent.* maximum grade is located on the .05 per degree standard. From Agua Zarca over the hill to Nogalis, which is double that maximum, or nearly so, where I expected another engine of the same class to haul the train that came from Imuris, I used instead of .04 compensation which would be the rule for a single train .05 for the double-header, and this seemed to be all right, with what little time I had to test the matter before I left the road.

During the winter of 1878–9, after we had our experience from La Junta to Raton above mentioned, we figured out the mathematical reasons why this theory is correct. This paper has been mislaid, and pressure of

business has prevented its reproduction. There is no doubt that the proposition is correct and can be mathematically proven, and while I am aware that it is not easy to attempt to refute the numerous authorities which are springing up from time to time to prove that the resistance is proportional to the radius, I think we can afford to take the chances, and if we cannot prove it mathematically we shall have to invite them to ride over the road and let practice prove to them that mathematics is mistaken.

There is one more point that I may be able to add a little later. I find that the Mexican Central Railway from El Paso to Chihuahua has been located on a .7 maximum grade with .04 compensation, whereas we would have allowed by our rule .06. I have not had time yet to satisfy myself fully what the effect is, but the two or three locomotive engineers that I have questioned say that there is an appreciable dragging of the train where the curves are on the maximum grade.

Rules for Construction Sonora Railway, issued by William R. Morley, M. Am. Soc. C. E., Chief Engineer.

Rules and regulations for location and construction, for the particular use of the engineers:

Estimates for Comparison of Lines.

Location or change will be made on following basis:

1. On operating divisions with a maximum ruling grade of 0.70 per station:

Value of saving distance, per foot	$3 00
" " curvature, per degree	5 00
" rise and fall, per foot	50 00

2. On operating divisions of maximum ruling grade from 0.7 per station to 1.4 per station:

Value of saving 1 foot distance	$4 00
" " 1 degree of curvature	6 00
" " 1 foot rise or fall	62 00

3. On operating divisions with maximum ruling grade from 1.4 per station to 2.4 per station:

Value 1 foot distance	$5 00
" 1 degree of curvature	7 00
" 1 foot rise or fall	75 00

NOTE.—In the foregoing values of distances figures refer to short distances, such as would not affect the number of stations, tanks, side tracks, etc., on the road. Long distances, say 10 miles or more, should be estimated about 65 *per cent.* higher per foot. It should be borne in mind that these values are "operating values" only, and do not include cost of construction, so that any difference in estimate of cost must be taken separate account of.

Grades.

1. Each operating division will have its maximum grade established prior to location, after which it must not be exceeded, unless in special cases, and by order of the Chief Engineer.

2. *Compensation of Grades for Curves.*—No grade will be admissible on any curve that is not reduced below the maximum on its operating divisions by at least the rate of the following table:

Rate of max. grade,		.00 to .70	per 100 feet,		.06	per 100 feet	per degree.	
"	"	.70 to 1.60	"	"	.05	"	"	"
"	"	1.60 to 3.00	"	"	.04	"	"	"

Curvature.

1. *On Main Line* 10° *per* 100 *Feet will be Maximum Admissible.*—Each operating division will have its maximum curvature established prior to location.

2. *Easing Off Sharp Curvature.*—On all curves of 6° per 100 feet and upwards the curve should be eased off by putting in at least 100 feet of lighter curve at each end. As a rule, do not let the taper curves exceed in rate one-half of the central curve, although in extreme cases it may rate as high as 6°, but no more. The longer the taper curves the better. In cases of very long, sharp curves of 8° or 10° a double compound at each end of, say, 3° and 6° for 100 feet or more each, is desirable.

Vertical Curves.

1. When grade changes occur in which the change exceeds .02 per 100 feet, the following rule will be observed:

2. *Rule for Vertical Curves.*—When one grade rises and the other falls, drop the grade at the point of change by a quantity equal to half the *sum* of the rates per station for each grade. One hundred feet either side of the point of change drop the grade a distance equal to one-quarter of the distance first dropped.

Example.

Elevation of grade at a summit (Station 300, for instance) is 100.00. Rate on one side $+1.00$, on the other -0.50. Then $\frac{1.00+0.50}{2}=0.75$ correction for the middle station, $100.00-0.75=99.25$, corrected elevation at Station 300.

Elevation at Station 299 (rate $+1.00$) $=99.00$,
301 (rate $-$ .50) $=99.50$.

$\frac{0.75}{4}=0.19$ correction for side stations.

$99.00-0.19=98.81$ corrected elevation at Station 299.
$99.50-0.19=99.31$ " " " 301.

3. When both grades are plus, the correction must be a quantity equal to half the difference of the two rates. The elevation to be dropped if the heavier grade precedes, and raised if the lighter precedes.

4. When both grades are minus, the correction must be a quantity equal to half the difference of the two rates. The elevation to be raised if the heavier grade precedes, and dropped if the lighter precedes.

5. When the difference or sum at a change of grade is less than .02 the rounding may all be done in 200 feet by raising or lowering the grade at the centre or changing point by one-half the sum or difference, as the case may be.

6. Grade elevations will be written in the cross-section book, with corrections for roundings, and estimates be based on these corrections.

7. Track engineers will be furnished with profile and grades of the whole line and grade elevations of all vertical curves. The vertical tangents may be run in by the transit, but the curves should be set by the level.

Superior Elevation of Outer Rail on Curves.

1. Outer rail on curves on main line must be elevated at the rate of .04 per degree for the gauge 4′ 8½″. In staking out work Division Engineers will stake out the roadbed on curves at this rate = 0.1 per degree for width of roadbed of 12 feet, of which outer crown of roadbed will be elevated one-half above and the inner crown one-half below the true grade of centre line. Grade stakes for finishing the work will be set accordingly, allowing 50 feet per degree for run off at end of curve.

2. Track engineers will set track grades on the same basis, *i. e.*, outer grade stake must set one-half the super-elevation above true centre grade, and the inner grade stake one-half the super-elevation below centre grade.

DISCUSSION ON CURVE COMPENSATION.

A. A. Robinson, M. Am. Soc. C. E.—Mr. Morley's letter was dictated to a stenographer, and evidently with some haste, so that the conclusions from observed facts are not all clearly stated, and the letter contains some inaccuracies which he would have been quick to correct, if he had carefully revised what was written.

Mr. Morley's practice upon the "Veta Pass Line" (Denver and Rio Grande Railway) can hardly be justified by theory, and I am sure that observation cannot fail to show a marked difference between the motive power required to pull a train upon a curve of 521 feet radius, when the rate of ascent has been properly lessened to compensate for the resistance due to curvature, and that required upon a curve of 573 feet radius, when no compensation for curvature is made.

In March, 1878, the location of the New Mexico Extension of the Atchison, Topeka and Santa Fé Railroad, from La Junta, Colorado, southward toward Trinidad and Santa Fé, was commenced under my direction, the surveys being pushed simultaneously from La Junta southward, from the summit of the Raton Mountains northward toward Trinidad and La Junta, and from the summit southward towards Santa Fé.

Preliminary surveys developed the fact that the different rates of maximum or ruling gradients mentioned by Mr. Morley, were either made necessary by the topography, or could be economically used in the proposed system of train service for the operation of the road.

Before making a final location of any part of this line, it was necessary to decide in what ratio gradients should be lessened on curves so that the force of gravity upon the lessened gradient, considered as a resistance to the movement of an ascending train, added to the resistance due to curvature, should not exceed the gravity resistance of the maximum gradient on a straight line, and upon the authority of the experiments of Colburn and Latrobe, as related by Mr. Vose in his Manual for Railroad Engineers, I decided to consider each degree of curvature as the equivalent, in point of resistance to the movement of trains, of 0.05 of a foot of ascent.

During the progress of the construction of this part of the road, and after its completion, it was matter for special interest to myself and Mr. Morley to observe the effect of this compensation.

We found, as stated by Mr. Morley, that:

1st. Upon maximum gradient of 0.6 per cent., where a full train consisted of 30 to 32 loaded cars, the compensation was hardly sufficient.

2d. Upon maximum gradient of 1.13 per cent., with full trains of 18 to 20 cars, it was fully sufficient; while

3d. Upon maximum gradient of 3.4 per cent., with full trains of 7 to 8 cars, it was evidently greater than was needed.

Subsequent discussion of the subject between my assistants and myself developed the following ideas and suggestions, which I give as probably being what Mr. Morley incorrectly refers to as a mathematical solution.

The resistance to the movement of trains which is caused by the curvature of railroad tracks is a force which is affected by many varying circumstances and conditions, and it cannot be satisfactorily determined by mathematical formula, except for the one particular set of circumstances and conditions which may be assumed.

For example, suppose a curved track is laid *level*, that is, with the top of the rails as nearly as may be in a horizontal plane; upon this track a locomotive without leading trucks or tender moves slowly, say at the rate of 1 or 2 miles per hour. In this case there is a curve resistance pure and simple due to the friction of the wheel flanges against the rails of the curved track and of the "tread" of the wheels upon the top of rails caused by the constant change in the direction of motion. This resistance is directly proportional to the degree or rate of curvature, or inversely proportional to the radius.

But suppose that instead of moving slowly the locomotive runs at the rate of 35 miles per hour. The centrifugal force of the moving train will then be a considerable factor in the problem.

It must be resisted by the pressure of the wheel flanges against the rails, and the resistance to the forward movement of the engine will thus be increased.

In practice, it is the custom to counteract the centrifugal force of moving trains by raising the outer rail of curves above the inner rail, so that the top of the rails lie in the surface of an inverted cone. This super-elevation of the outer rail for any speed of train should be such that the components of the force of gravity and the centrifugal force acting in lines parallel with the inclined surface of the track, shall be equivalent and counteracting, and it is customary to calculate the super-elevation of the outer rail for a speed of 30 or 35 miles per hour. If, then, the supposed locomotive, instead of running at the rate of 35 miles per hour, should run but 15 miles, while the super-elevation of the outer rail was suited to the greater speed, we should find the resistance problem still further complicated.

Another element of the curve resistance is the greater length of the outer rail, which requires that one or the other of the wheels fixed upon an axle should slide over a distance equal to this greater length.

It is customary to attempt to obviate this difficulty by "coning" the car wheels, but this device, so beautiful in theory, is of questionable utility in practice.

The gauge of track, as compared with that of the wheels of the locomotive, will also affect the curve resistance.

Considering only the supposed locomotive, the resistances due to curvature as mentioned above will be more or less directly functions of the degree or rate of curvature; but suppose that behind the locomotive we attach a car. A diagram, page 193, will show the reciprocal action of the tractive force of the locomotive and the corresponding resistance of the car as affected by the curvature of the track.

The engine in pulling the car will act through the coupling at the middle of the rear end of its rigid frame, and the force exerted at this point will be transmitted through the frame of the car to the kingbolts and centre bearings of the car trucks.

The line *ET* from the rear coupling of the locomotive to the centre bearing of the nearest truck is in the direction of, and may be assumed

to represent the tractive force, of which the component Eb acts in the direction of the motion of the truck, and Tb at right angles to that direction, tending to pull the truck against the inner rail of the curved track.

In the same way ET may represent the resistance to traction and be resolved into Ta in the direction of the motion of the engine, and Ea at right angles to the same, the latter component acting to draw the rear drivers of the engine against the inner rail.

In a similar manner, the tractive force acting from T through the frame of the car to T', and the corresponding resistance acting at T', will have components which tend to draw the trucks toward the centre of the curve, and so on throughout the length of the train.

The resultant of all these forces will produce a total train resistance which will be a function not only of the rate of curvature and of the gross tonnage of the load behind the locomotive, but also of the number of cars in the train.

It needs no argument to prove that the tenth car in a train will produce a greater resistance to traction than the first car. This follows from the fact that the line from E to the centre bearing of the first truck of the tenth car makes a greater angle with the directions of the motion of the engine and of the truck, so that while the component of the tractive force which acts in the direction of the motion of the truck must be the same for the tenth car as for the first, the component which tends to pull the truck toward the centre of the curve will be greater for the tenth car, and hence the force itself must be greater.

It is equally clear that a train of ten cars will produce a resistance greater than ten times that of a single car, and that the resistance of a train of thirty cars will be greater than three times that of a train of ten cars.

It follows that upon a railroad, or any division of a railroad, where locomotives can pull thirty cars, the ratio of compensation for the resistance due to curvature should be greater than upon a road or division where engines can pull but ten cars, and as the principal element in the determination of the weight of trains which engines can pull is the ruling gradient of the road or division, it follows that the ratio of compensation for the resistances due to curvature should vary inversely with the ruling gradient.

It will be observed from the foregoing that this problem is affected by circumstances to which no fixed rules will apply.

We therefore have to adopt rules that will cover the common practice of engineers upon American railroads. Such rules must necessarily be empirical, therefore but little can be said except to announce that after an experience ranging over fourteen years in railroad construction and operation upon maximum grades varying from 20 feet per mile to those of 316$\frac{8}{10}$ feet per mile, and with all classes of locomotives—"Standard American," "Mogul," "Consolidation," and "Ten-Wheelers"—we have in our practice settled upon the following rules for the compensation for curvature :

Rate of maximum grade,	0.0 to 0.6	per hundred;	compensation	0.06	per 100 ft. per degree.
" "	0.6 " 1.6	"	"	0.05	" "
" "	1.6 " 3.0	"	"	0.04	" "

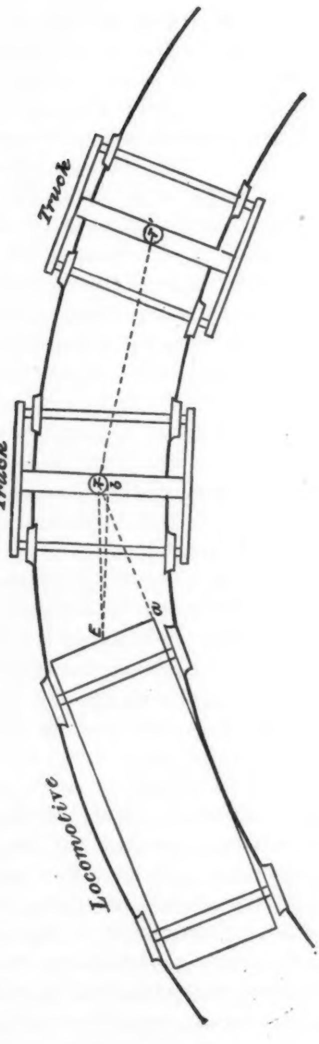
It is evident that the friction on curves increases with the number of cars, or more properly with the number of wheels; it should therefore be remembered that for engines of great power, greater allowance for curvature should be made.

In order that a road may be economically laid out, the class of engines to be used should be decided beforehand, but as the tendency is to heavy engines, it is the duty of engineers to adopt safe limits for curve compensation.

We find that the heavier engines "Mogul" and "Consolidation" are assigned to the mountain grades, while the lighter machines of the American standard pattern, with four drivers, go on the light grades, and the rate of compensation given covers such a disposition of power.

LEWIS KINGMAN, C. E. (by letter).*—In regard to compensation on curves—on the Atlantic and Pacific Railroad, first under Mr. A. A. Robinson and then under Mr. H. R. Holbrook, our instructions were to compensate .05 per degree on all curves alike. On that road from Winslow Section No. 274 to the Colorado River Section No. 574, I had all the curves eased off. Ten degree curves were used as a maximum. In running a ten degree curve I first made one station

* This discussion is from a letter from Mr. Lewis Kingman, Chief Engineer of the Chihuahua Division of the Mexican Central Railroad.


Truck
F
Truck
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Locomotive

(100 feet) of 3 degrees 20 minutes; then 100 feet of 6 degrees 40 minutes, then compounded to 10 degrees. The same rule was adopted in leaving the curve at the other end. For an 8 degree curve there was, first, one station of 2 degrees 40 minutes; then one of 5 degrees 20 minutes. For a 6 degree curve, I commenced with 100 feet of 3 degree curve and then compounded to 6 degrees, easing the curve off in the same way. I persisted in this and had it carried out, and found but very few places where it could not be done. I think the increased cost of such a location hardly worth mentioning. There are places where, of course, a little more work is involved, but if the line is carefully adjusted the addition will be slight. There are other ways of running in and lightening curves, but in practice in a mountain region I think this is, perhaps, as good and easy a method as any other.

I have watched the trains on curves and tangents closely, and will give one particular instance: During December last I went with a boarding train from the spur at Aubrey Station to move to Tampai Station. There were 42 cars, mostly box cars (I think all but one tool car were box cars). We had two engines, each of 35 tons; they were both at the rear end of the train. On tangent they were able to make about 6 miles per hour. On tangent and 75 feet per mile grade they passed over 4 degree and 5 degree curves without any perceptible change in speed. But when there came an 8 degree curve (eased by 100 feet of 2 degrees 40 minutes, and 100 feet of 5 degrees 20 minutes into the 8 degree), all to the left, the train slowed up, and as it passed upon a short tangent of about 200 feet and then upon a curve of 2 degrees 40 minutes and 5 degrees 20 minutes, to an 8 degree curve, all to the right, the front of the train passed nearly over, but all came to a stand, and the engineers backed and pushed for an hour or more and could not go 10 feet further until a third engine came up. This satisfied me, as the track had been surfaced up and was in good shape. I think, that had one engine been pulling and the other pushing, they might have done better. This train was 1 500 feet long, and it was nearly all on the *S* before it stopped.

In my opinion, there is no question but that the compensation should vary with the maximum grade or length of trains run. The size or weight of the locomotives used, of course, determines the length of the train as well as the grade. Observations I have made lead me to believe that, taking the ordinary locomotives used, the adjustment of the com-

pensation for a 52.8 feet per mile maximum grade should be about as follows:

1 degree curve ..	.035 per degree.	6 degree curve ..	.06 per degree.
2 " " ..	.040 "	7 " " ..	.065 "
3 " " ..	.045 "	8 " " ..	.07 "
4 " " ..	.050 "	9 " " ..	.075 "
5 " " ..	.055 "	10 " " ..	.08 "

For a 75 feet per mile maximum grade, I think that the compensation should be as follows:

1 degree curve...	.030 per degree.	6 degree curve...	.050 per degree.
2 " " ..	.030 "	7 " " ..	.055 "
3 " " ..	.035 "	8 " " ..	.06 "
4 " " ..	.04 "	9 " " ..	.065 "
5 " " ..	.045 "	10 " " ..	.07 "

For a 100 feet per mile maximum, I think that 1 degree curves should be compensated .03 and 10 degree curves about .06.

I think a very long 10 degree curve should be compensated more than a short one.

I believe if this was done and an observer should take a passenger train of two coaches and baggage car, he would notice that the train picked up or increased its speed on the heavy curves. On the other hand, let an engine with a long train of empty cars start up, and I think the train would move evenly. Our roads should be compensated for long freight trains and for the freight traffic, and not for the passenger trains, which carry a large reserve of power.

I am aware that we lack careful tests, which might be made in such a way, I think, as to clear up this whole question. With the large amount of capital invested in railroads in the United States, it is too bad that these tests cannot be made under all varying circumstances.

A. M. Wellington, M. Am. Soc. C. E.—Mr. Morley's rules for location, although prepared for another portion of the same system of lines as that on which I have had charge of location, have never heretofore been seen by me and were independently prepared. The subjoined extracts from the instructions which I prepared for use in the southerly and central sections of the Mexican Central Railway lines will show that they are, nevertheless, in tolerably close agreement.

With regard to the important question of reducing grade on curves, the rule adopted by both Mr. Morley and myself was the same on the

higher grades—viz., .04 per degree of curvature—but this Mr. Morley increased to .06 per degree of curvature on the lower grades. This may have been with the idea that the curve resistance per ton would be higher with the longer trains appropriate to lower grades, a view which I advocated myself in a treatise on the theory of location published some years since. I was supported in this view by one of the most eminent members of this Society, as well as by various published formulæ, etc. Further investigation, however, both experimental and theoretical, has satisfied me that no sensible difference due to this cause exists.

On the other hand, Mr. Morley's idea may have been that a larger compensation should be allowed on lower grades because it could more easily be obtained, in which case he was evidently right. The truth is that no absolutely fixed rate of compensation to be invariably applied in all cases can or ought to be fixed. When there is no great difficulty in using any compensation we please without increasing the tangent grade—as on most mountain grades not exceeding 1 000 feet vertical rise and proportionally for lower rates of grade—it is plainly proper to adopt a liberal rate of compensation. When, as frequently happens in difficult country, every decrease in rate of grade on curves means a corresponding increase on tangents, it is then plainly inexpedient to adopt a higher rate of compensation than is *certainly* necessary to prevent excess of resistance on curves. In this connection, I may add that I am satisfied the rate of compensation I have been quoted as advocating—and in part with justice—of 0.1 per degree of curvature, is higher than is ever necessary, unless in certain cases at stations, or when it becomes a question whether to admit certain sharp curves at all. From such information as I have been able to gather, it seems to me extremely probable that curve resistance is materially greater at very slow speeds; and experience on the New York Elevated Railroads, and on many other lines with very sharp curves, as well as modern determinations of the laws of friction, make it extremely doubtful whether the curve resistance increases even so fast as the degree of curvature. It is unfortunate that further and more complete experiments than now exist cannot be made. So far as I can ascertain, there is little, if any, trustworthy experimental evidence tending to prove that the resistance on a 20° curve is twenty times as much as on a 1° curve, while there is much of a very positive character to indicate the contrary. Among the latter may perhaps be included the observations of Mr. Morley and Mr. Rob-

inson, as chronicled in the beginning of Mr. Robinson's discussion above, in respect to a less reduction of grade for curvature being required on high grades than on low ones. Those gentlemen evidently took great pains in observing the facts, but it is important to remember that more than one explanation of them may be possible; granting the entire correctness of the observations themselves, which it must have been a sufficiently delicate matter to make correctly without the assistance of exact velocity records. It is a fact that on the lines on which these observations were made, the curvature on the low grades is in general very easy and the curvature on the high grades tolerably sharp. *If*, therefore, the resistance is, as suggested, less per degree on the sharper curves, the whole phenomena are accounted for without the necessity of assuming that the curve-resistance per ton increases with the length of the train.

Extracts from Instructions for the Guidance of Surveys and Location for the Mexican Central Railway Company.—A. M. Wellington.

In order to secure uniformity and intelligibility in maps and records, and to facilitate the work of securing correct location, the following general instructions are issued for the guidance of location and work connected therewith.

The alignment turned in is expected to conform to the following conditions:

Distance.—For minor variations amounting at most to no more than 3 or 4 kilometers in a division, not more than $20 nor less than $7 per meter will be expended to save distance, depending on the probable traffic; the cost of track, estimated at $6 per meter, being included. Larger variations materially affecting the operation of the work are not intended to be included under the above.

Rise and Fall.—No considerable expenditure will be incurred to avoid gentle undulation of grade of any length on rates not exceeding 0.5 per cent. and not changing abruptly from ascent to descent.

Grades differing more than 0.4 per cent in rate must not be brought to a sharp intersection, but connected by easy vertical curves, at least one station long for each 0.2 of difference in rate of grade.

Undulations of grade on any rates whatever, if the transition from one grade to another be eased off as above directed, will not be regarded as

an evil justifying considerable expenditure to avoid, if they do not exceed 4 meters in vertical depth.

Deeper undulations than this, on such grades, should be valued at not less than \$300 nor more than \$1 500 per vertical meter, *in excess of 4 meters* depending both on the probable traffic and on the rates of grade.

From 30° to 40° of curvature per vertical meter in excess of 4 meters is to be preferred to such sags in the grade.

CURVATURE.—The justifiable expenditure to take out a curve altogether will be determined by adding 10° to the actual number of degrees contained in it. Expenditure to secure long tangents will not be incurred in excess of that warranted by the preceding instructions, unless the modification is such that it will also sensibly increase the safe speed of trains and the distance at which obstructions are visible.

Curves of 5° or more must in all cases be connected with their tangents by transition curves, according to the special instructions given herein, wherever construction has not actually been begun.

Reversed curves will not be used in any case. The tangent must always be made at least 50 meters long by decreasing the radius, if not otherwise possible, in order to give room for the transition curves to meet at a common point.

(On certain sections of very difficult work a few tangents only 20 meters long have been admitted.)

To the latter, although it is technically a reversion, there is no objection.

RADIUS OF CURVATURE.—The admissible expenditure to reduce the radius of curvature is given in the following tables, and will not be exceeded. The sharpest curves will only be admissible in connection with the heavier grades, where they can be properly reduced, so as to avoid limiting the length of train. The maximum limit of curvature, as fixed by this consideration, will be taken to be as follows :

On a maximum grade:	0.5,	0.6,	0.7,	0.8,	0.9,	1.0,	1.2,	1.4,	1.6, per cent.
Maximum curve on a level:	6°	7°	8°	9°	10°	11°	12°	13°	14°

Maximum Admissible Expenditure to Increase Radius of Curvature on any part of the Main Line.

Curves to be Substituted.		Curve to be Avoided and Admissible Expenditure.									
Degree.	M. Radius.	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
2°	716.23	$300	$600	$900	$1 400	$2 100	$3 000	$4 100	$5 400	$6 900	$8 600
3°	477.52	......	300	600	1 100	1 800	2 700	3 800	5 100	6 600	8 300
4°	358.17	......	......	300	800	1 500	2 400	3 500	4 800	6 300	8 000
5°	286.56	......	......	......	500	1 200	2 100	3 200	4 500	6 000	7 700
6°	238.84	......	......	......	......	900	1 600	2 700	4 000	5 500	7 200
7°	204.75	......	......	......	......	......	900	2 000	3 300	4 800	6 500
8°	179.19	......	......	......	......	......	......	1 100	2 400	3 900	5 600
9°	159.31	......	......	......	......	......	......	......	1 300	2 800	4 500
10°	143.42	......	......	......	......	......	......	......	......	1 500	3 200
11°	130.40	......	......	......	......	......	......	......	......	......	1 700

Minimum Expenditure to Increase Radius of Curvature on Branches of Lighter Traffic.

Curves to be Substituted.		Curve to be Avoided and Admissible Expenditure.										
Degree.	M. Radius.	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°
3°	477.52	$150	$200	$300	$400	$500	$700	$1 000	$1 400	$1 900	$2 500	$3 200
4°	358.17	......	100	200	300	400	600	900	1 300	1 800	2 400	3 100
5°	286.56	......	......	100	200	300	500	800	1 200	1 700	2 300	3 000
6°	238.84	......	......	......	100	200	400	700	1 100	1 600	2 200	2 900
7°	204.75	......	......	......	......	100	300	600	1 000	1 500	2 100	2 800
8°	179.19	......	......	......	......	......	200	500	900	1 400	2 000	2 700
9°	159.31	......	......	......	......	......	......	300	700	1 200	1 800	2 500
10°	143.42	......	......	......	......	......	......	......	400	900	1 500	2 200
11°	130.41	......	......	......	......	......	......	......	......	500	1 100	1 800
12°	119.58	......	......	......	......	......	......	......	......	......	600	1 300
13°	110.42	......	......	......	......	......	......	......	......	......	......	700

Larger expenditures than are justified by the preceding tables will in no case be incurred at the present time, but, on the other hand, wherever particularly sharp curvature is unavoidable, under the preceding rules, the line will, so far as possible, be located with reference to improvements hereafter, when traffic justifies the expense.

COMPENSATION FOR CURVATURE.—All curves on maximum grades will have the grade reduced on them by .06 per degree of curvature, with 20 meter chain (= .04 per degree of curvature, with 100 feet chain).

It is unnecessary to place the break of grade precisely at the P. C. or P. T. Take the nearest even station always. Connect all breaks in rate of grade exceeding 0.4 per cent. by an intermediate grade, as heretofore directed. On all curves at or very near to regular stations and stopping points, the reduction of curvature should be double the above.

GRADIENTS.—The fact that certain heavy grades may be required at one or more points on a division will not be regarded as justifying the use of heavy grades throughout, provided that such grades do not exceed, in all, one-fourth or one-fifth of the length of an operating division, and are so situated that they can advantageously be operated by assistant power, or, if the traffic be very light, by cutting trains in two. In such cases the grades should be adjusted to each other, so far as possible, according to the table for assistant power grades.

A nearly level plane for a siding should in such cases be located at top and bottom of such assistant power grades, even if the sidings are not at once constructed. The maximum grade at all stations and stopping places should be reduced at least 0.25 per cent. for at least 500 meters (or 1.25 meters drop in all, from regular grade), to compensate for the resistance of starting.

Particular attention will be paid to this at water stations, on long maximum grades.

MOMENTUM GRADES.—On short sections of maximum grade not exceeding two kilometers in length, a maximum deviation in the grade line of *three* meters *below* and *four* meters *above* the straight grade line between the two ends of the plane will be permitted, in order to reduce work, and especially to avoid rock cutting or heavy fills, relying on the momentum of the train to equalize the resistance of the various grades. Especial care, however, must be taken to have easy transitions from one grade to another, in order that the change of velocity may be gradual, In such case, the rate of the intermediate grade is unimportant, since

the total work to be performed by the engine on the entire plane remains the same. Such momentum grades, however, must in no case be introduced, unless an initial velocity of 20 or 25 miles an hour at the foot of the plane can be relied on. In that case, the effect of a 3 meter sag is to increase the velocity 2 to 3 miles per hour, and of a 4 meter summit to decrease it 5 or 6 miles per hour.

The train will in any case leave the plane at the same velocity as if the grade were straight, only in the latter case the speed would be uniform throughout.

WM. H. SEARLES, M. Am. Soc. C. E.—It has been pretty well ascertained by experiment, as well as proved by theoretical considerations, that for *one car* moving on a curve, the resistance of the curve varies inversely as the radius. Not so, however, when we consider a train of cars; for, in addition to the sum of the resistances of the cars taken singly, we experience a resistance due to the angle existing between the cars on a curve. The tractive force, therefore, at the head of a train on a curve, must increase more rapidly than the number of cars added to the train, in order to maintain uniform motion.

I propose to discuss the nature and amount of this increment to the resistance on curves. Suppose a train of cars equal in size and weight, and all equally loaded, moving on a curve at a uniform velocity. The last car develops a certain resistance, due to friction, to grade, and to curvature, which resistance we may denote by p_1, expressed in pounds per gross ton of the car and load.

The next car ahead develops the same amount of resistance on its own account, but the force applied to it in its own direction must be equal to this resistance, *plus* the resistance of the rear car multiplied by the secant of the angle between their directions. If we call this force (expressed in pounds per ton) p_2, and the angle between the cars α, then

$$p_2 = p_1 + p_1 \sec. \alpha.$$

Similarly, in a train of three cars, the force p_3 in pounds per ton necessary to apply to the forward car in its own direction is equal to the resistance of that car, *plus* the force p_2 multiplied by the secant of the angle α; or

$$p_3 = p_1 + p_2 \sec. \alpha;$$
$$= p_1 (1 + \sec. \alpha + \sec.^2 \alpha).$$

So, in general, for a train of n cars, the force necessary to apply to the forward car in its own direction to maintain uniform motion is, per ton,

$$p_n = p_1 \; (1 + \text{sec. } \alpha + \text{sec.}^2 \alpha + \&\text{c.} + \text{sec.}^{n-1} \alpha).$$

But sec. $\alpha = 1 +$ exsec. α, and making the substitution we have

$p_1 = p_1;$

$p_2 = p_1 \; (2 + \text{exsec. } \alpha);$

$p_3 = p_1 \; (3 + 3 \text{ exsec. } \alpha + \text{exsec.}^2 \alpha);$

$p_4 = p_1 \; (4 + 6 \text{ exsec. } + \alpha \; 4 \text{ exsec.}^2 \alpha + \text{exsec.}^3 \alpha);$

$$p_n = p_1 \left(n + \frac{n \; (n-1)}{2} \text{exsec.} \alpha + \frac{n \; (n-1)\,(n-2)}{2 \times 3} \text{exsec.}^2 \alpha +, \&\text{c.} \right)$$

the co-efficients of the several powers of exsec. α being formed according to the binomial theorem.

Since the external secants of small angles are to each other as the squares of the angles very nearly, if we select the external secant of 10°, which is .0154, we have by a simple proportion for any small angle, α expressed in degrees:

$$\text{exsec. } \alpha = .000154 \, {}^2\alpha.$$

Making this substitution in the last expression, and assuming at the same time that three cars will equal 100 feet in length, whence $\alpha = \frac{D}{3}$ or one-third the degree of curve, we derive the following general formula:

$$p_n = n \, p_1 + n p_1 \left[\begin{array}{l} (n - 1).\text{V}, 85555 \; D^2; \\ + \; (n - 1) \; (n - 2).\text{X}, 488 \; D^4; \\ + \; (n - 1) \; (n - 2) \; (n - 3).\text{XV}, 21 \; D^6; \\ + \; \&\text{c}. \end{array} \right]$$

The Roman numerals are used to express the number of *naughts* between the decimal point and the significant figures of the decimal co-efficient of the powers of D.

This formula, then, gives us the total tractive force p_n, expressed in pounds per ton, necessary to be applied at the head of a train of n cars, moving at a uniform velocity on a curve, whose degree of curve is D, in terms of the total force p_1, expressed in pounds per ton necessary to move *one car* on the same curve at the same velocity. The quantity in brackets is, evidently, a co-efficient by which we may obtain the *increment* of resistance due to the length of train on a curve D. To facilitate the further study of this subject, I have been at some pains to tabulate

TABLE OF VALUES OF THE CO-EFFICIENT *K*, FOR FINDING THE INCREMENT TO THE RESISTANCE OF A TRAIN IN TERMS OF THE NUMBER OF CARS, AND THE DEGREE OF CURVE.

No. of Cars *n*.	5° Curve *K*.	Diff.	10° Curve *K*.	Diff.	15° Curve *K*.	Diff.	20° Curve *K*.	Diff.	25° Curve *K*.	Diff.
5	.0009	......	.0034	......	.0077	......	.0138	......	.0216	......
10	.0019	10	.0077	43	.0175	98	.0314	176	.0495	279
15	.0030	11	.0121	44	.0274	99	.0494	180	.0784	289
20	.0041	11	.0164	43	.0374	100	.0678	184	.1084	300
25	.0052	11	.0208	44	.0476	102	.0866	188	.1395	311
30	.0062	10	.0251	43	.0579	103	.1059	193	.1717	322
35	.0073	11	.0296	45	.0683	104	.1256	197	.2050	333
40	.0084	11	.0341	45	.0789	106	.1458	202	.2396	346
45	.0095	11	.0386	45	.0896	107	.1664	206		
50	.0106	11	.0431	45	.1004	108	.1875	211		
55	.0116	10	.0476	45	.1114	110				
60	.0127	11	.0522	46	.1225	111				
65	.0138	11	.0568	46	.1338	113				
70	.0149	11	.0614	46	.1452	114				
75	.0160	11	.0660	46						
80	.0171	11	.0707	47						
85	.0182	11	.0754	47						
90	.0193	11	.0801	47						
95	.0204	11	.0849	48						
100	.0215	11	.0896	47						

No. of Cars *n*.	30° Curve *K*.	Diff.	35° Curve *K*.	Diff.	40° Curve *K*.	Diff.	45° Curve *K*.	Diff.	50° Curve *K*.	Diff.
5	.0313	......	.0428	......	.0563	......	.0717	......	.0893	......
10	.0722	409	.0998	570	.1326	763	.1712	995	.2161	1268
15	.1153	431	.1609	611	.2163	837	.2828	1116	.3621	1460
20	.1607	454	.2264	655	.3078	915	.4078	1250	.5298	1677
25	.2085	478	.2967	703	.4080	1002				
30	.2588	503	.3719	752						
35	.3117	529								

a series of values for the quantity in the brackets, and which I will denote by the letter K, for curves ranging from 5° to 50°, and for trains ranging from 5 cars to 100 cars.

An examination of the formula shows us that while K varies with the even powers of D and of n, the numerical co-efficients of these powers above the square decrease so rapidly that the higher powers can have little effect on the value of K, unless either D or n be great; that is, unless we have a very sharp curve or a very long train.

In the table, we see that for a 5° curve the differences of the value of K are nearly constant, while for a 20° curve, and upwards, they have a decidedly increasing ratio.

The value of p_1 is determined only by experiment. If we adopt the usually accepted values for resistances, we have p , the total resistance of a single car in pounds per gross ton, composed of 7.5 pounds for level tangent, $22.4G$, for a rising grade, G expressed in feet per 100 feet, and $0.5D$ for a curve, D being the degree of curve expressed in degrees. Thus:

$$p_1 = 7.5 + 22.5G + 0.5D$$

for one car, and

$$p_n = np_1\ (1 + K)$$

for the total train resistance in pounds per ton. It is to be observed that while the primary curve resistance is say $0.5D$, and independent of the grade resistance, the *increment* to the curve resistance which we are seeking is a product of the entire resistance due to grade and curve by our co-efficient K, and, when found, is to be added to the primary curve resistance to get the total curve resistance. Therefore, for a given train, the curve resistance increases as the grade grows steeper, but, on the other hand, the increment is less as the number of cars is less, which is necessarily the case in steep grades. We shall see presently what the ultimate effect will be with a given engine.

Let us now assume a train of 20 cars, weighing 20 tons each, and ascertain the resistances it will encounter on various grades and curves, the cars measuring 3 to 100 feet. The following table indicates the method of obtaining resistances. Assuming, for example, the grade of 0.67 per station, we find the proper co-efficient K for 5° and multiples of 5°; then write the partial resistances for level tangent, for grade and for one car on the curve, all in pounds per ton; add these together, multiply by K, and set down the product in the column for incre-

ment. Add the four columns together for the total resistance in pounds per ton. This, multiplied by the weight of train in tons, gives the aggregate resistance of the cars. Adding together the third and fourth columns of the partial resistances gives the curve resistance in pounds per ton; this, divided by D, gives the same per degree, and dividing again by 22.4 gives the equivalent grade in feet per station per degree, as shown in the last column. This is, therefore, the reduction in grade or flattening that a 0.67 grade would require in the case assumed.

TABLE OF RESISTANCES—TRAINS OF 20 CARS OF 20 TONS EACH, LENGTH 667 FEET, GRADE 0.67 PER STATION.

Degree of Curve.	Co-efficient.	PARTIAL RESISTANCES.				TOTAL RESISTANCE.		CURVE RESISTANCE.		
D	K	Level Tang.	Grade G	Curve. 1 Car.	Increment.	Pounds per Ton.	Per Train, Pounds.	Total Lbs. per Ton.	Lbs. per Ton per Degree.	Equiv. Grade, ft. per 100 per Degree.
5	.0041	7.5	15.0	2.5	.10	25.10	10 040	2.60	.520	.023
10	.0164	"	"	5.0	.45	27.95	11 180	5.45	.545	.024
15	.0374	"	"	7.5	1.12	31.12	12 448	8.62	.575	.025
20	.0678	"	"	10.0	2.20	34.70	13 880	12.20	.610	.027
25	.1084	"	"	12.5	3.79	38.79	15 516	16.29	.651	.029
30	.1607	"	"	15.0	5.03	42.53	17 012	20.03	.701	.031
35	.2264	"	"	17.5	9.06	49.06	19 624	26.56	.759	.034
40	.3078	"	"	20.0	13.08	55.58	22 232	33.08	.827	.037
45	.4078	"	"	22.5	18.35	63.35	25 340	40.85	.908	.041
50	.5298	"	"	25.0	25.17	72.67	29 068	50.17	1.003	.045

Proceeding in a similar manner for other grades, and for other lengths of train or number of cars, we obtain results which are summarized in the third table. The single line drawn through this table indicates the limits to the capacity of one consolidation engine; the double line, the limit of two, hauling the train.

We see at once that the curve resistance per degree increases with the grade, and also with the curvature for a given length of train. But, as Mr. Morley was of the opinion that the curve resistance per degree is less on the heavier grades, owing to the shortness of the trains, let us look at this side of the question a moment.

SUMMARY OF EQUIVALENT GRADES PER STATION PER DEGREE FOR 20 CARS OF 20 TONS EACH, ON VARIOUS CURVES AND GRADES.

GRADE.	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°
0.00	.023	.023	.024	.025	.026	.028	.030	.032	.035	.038
0.67	.023	.024	.026	.027	.029	.031	.034	.037	.041	.045
1.34	.024	.025	.027	.030	.032	.035	.038	.042	.047	.053
2.01	.024	.027	.029	.032	.035	.039	.043	.047	.052	.059
					FOR 30 CARS.					
0.00	.023	.024	.025	.027	.029	.030	.032			
0.67	.024	.025	.027	.030	.033	.036	.039			
1.34	.025	.027	.030	.034	.038	.042	.047			
2.01	.025	.029	.033	.037	.042	.048	.055			
					FOR 40 CARS.					
0.00	.023	.024	.026	.028	.031					
0.67	.024	.027	.029	.033	.038					
1.34	.025	.029	.033	.038	.044					
2.01	.026	.031	.036	.043	.051					

Suppose an engine of 60 tons, having a tractive force limited to 18 000 pounds, hauling its maximum number of loaded cars on a 20° curve; the curve being long enough to hold the entire train. Now, let the grade vary from a level to a 4 per cent. grade, and we have the results shown by table at head of the next page.

We find that under a constant tractive force, the increment, and consequently the total curve resistance, grows less as the grade increases, but very slowly indeed; so that the variations in the equivalent grade are hardly apparent except in the fourth decimal place.

TABLE OF RESISTANCES FOR A CONSOLIDATION ENGINE OF 60 TONS, HAULING ITS MAXIMUM TRAIN ON A 20 DEGREE CURVE.*

Grade. G	No. of Cars. n	Co-efficient. K	Partial Resistances.				Total Resistance, Lbs. per Ton.	Weight of Engine and Train, Tons.	Total Resistance per Train. P	Curve Resistance.		
			Lev. Tang.	Grade.	Curve, one Car, lbs. per Ton.	Increment.				Total Lbs. per Ton.	Lbs. per Ton per Degree.	Eq. Grade per Degree.
0.00	41	.1499	7.5	0.0	10.0	2.62	20.12	880	17 705	12.62	.631	.0281
.33	29	.1020	"	7.5	"	2.55	27.55	640	17 632	12.55	.6275	.0280
.67	22	.0753	"	15.0	"	2.45	34.95	500	17 475	12.45	.6225	.0278
1.00	18	.0604	"	22.5	"	2.42	42.42	420	17 816	12.42	.621	.0277
1.34	15	.0494	"	30.0	"	2.35	49.85	360	17 946	12.35	.6175	.0275
1.67	12	.0386	"	37.5	"	2.12	57.12	300	17 136	12.12	.606	.0270
2.01	10	.0314	"	45.0	"	1.96	64.46	260	16 760	11.96	.598	.0269
2.35	9	.0279	"	52.5	"	1.95	71.95	240	17 268	11.95	.5975	.0267
2.68	8	.0243	"	60.0	"	1.87	79.37	220	17 461	11.87	.5935	.0265
3.01	7	.0208	"	67.5	"	1.77	86.77	200	17 354	11.77	.5885	.0263
3.35	6	.0173	"	75.0	"	1.60	94.10	180	16 938	11.60	.580	.0257
3.68	5	.0138	"	82.5	"	1.38	101.38	160	16 221	11.38	.569	.0254
4.02	5	.0138	"	90.0	"	1.48	108.98	160	17 437	11.48	.574	.0255

We are forced to conclude, therefore, that the variation in compensation adopted by Mr. Morley is excessive and not founded on a true philosophy. This may almost be inferred from his paper, in which he admits that the .05 and .06 compensations were too great on the sharp curves, where the effect would naturally be conspicuous. He, however, used the .06 on low grades and flat curves, where its ill effect was not so easily discovered.

It would also appear that his compensation was everywhere excessive in amount, judging from the general experience on our first-class roads. If the resistances he gives really existed it would seem to indicate "that something was wrong with the track." It is not unlikely that on a rapidly constructed road over vast stretches of wild and mountainous country, there would be imperfections in the track of various sorts that would materially increase the resistance, especially on curves. This would

* NOTE.—When a given curve is shorter than the train, the proper value of the co-efficient K, to be selected from the first table, is determined by the number of cars that the length of the curve will hold.

naturally lead to a large compensation on curves detrimental to the road when the road-bed is perfected.

We have only to suppose a curve resistance of three-quarters of a pound per ton (instead of one-half pound), to bring up the compensation to .039 per station per degree, or just about Mr. Morley's lowest figure; but this will also reduce the number of cars in the maximum train. The figures in the last table would thus become, for level grade, 32 cars and compensation .0392; for 1.00 grade, 11 cars and .0382; for 4.01 grade, 4 cars and .0362.

Thus we may admit that his compensation of .04 was "about right" for sharp curves and heavy grades on that road; but if so, it was also about right for the flat curves and low grades, since with a constant engine force the variation in the resistance per degree is too small to be noticed, except by delicate apparatus. Just how great this variation is, may be seen in the following statement, in which we resume the resistance of one-half pound per ton per degree, one 60-ton engine and maximum train:

	Level.		2.01 Grade.		4.02 Grade.	
	n.	*Eq. gr.*	*n.*	*Eq. gr.*	*n.*	*Eq. gr.*
For 10° curves...	62	.0254	12	.0247	5	.0238
" 20° " ...	41	.0281	10	.0269	5	.0255
" 30° " ...	29	.0307	9	.0287	4	.0267

We thus have the extreme range for a train with one engine, from .0238 on a 10 degree curve and 4.02 per cent. grade to .0307 on a 30 degree curve and level or quite light grade. This theory confirms Mr. Morley's practical ideas in a general way, though the actual variation is less than he supposed.

With regard to widening the gauge in curves, I can see no advantage in this practice so far as a four-wheeled truck is concerned. On the contrary, I think the friction is rather increased by widening, as it leaves all the work of turning the truck to the flange of the forward out-

side wheel with an aggressive motion toward the rail, instead of giving part of the work to the flange of the rear wheel on the inner side with a retreating motion from the rail. The friction on the outer rail tends, by its retarding effect, to turn the truck in the wrong direction; but if friction were produced on the inside rail it would tend to turn the truck in the same direction as the curve. This statement is true also for a base of three or more wheels, provided the curve is flat enough to let the rear wheel flange be the first to come into contact with the inner rail. When a curve is so sharp that one of the intermediate wheel flanges touches the inner rail, it is time to widen the gauge, and only then.

The play of one-half inch ordinarily allowed in tangents is sufficient for a five-foot wheel-base on a 19 degree 30 minute curve, the rear axle being radial to the curve when the flange touches the inner rail, or for a ten-foot wheel-base on a 4 degree 45 minute curve.

The necessary play on any curve is readily found by the approximate formula:

$$.0000872 D l^2,$$

in which D is the degree of curve and l is the rigid wheel-base in feet, the result being in feet. From this result deduct the play allowed on tangents to find the necessary *widening* on the curve, which will be much less than is usually supposed. The wheels are assumed to be *not* coned, otherwise a wheel could not run comfortably with its flange in contact with the inner rail.

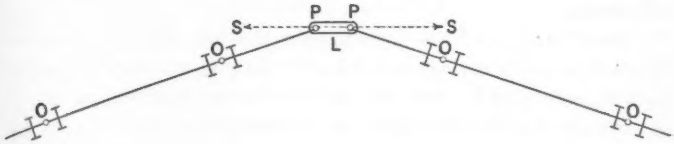
A. M. WELLINGTON, M. Am. Soc. C. E.—I conceive that Mr. Searles, careful theoretical discussion of the problem is vitiated throughout by a fundamental error in the premise on which he bases his mathematical reasoning; the error consisting in applying processes which are only correct for statical forces, or mere stresses, to dynamic energy or power proper. It is not true at all, or, if true, it is a fact which must be proved and not assumed, that "we experience a *resistance* due to the angle between the cars on a curve in addition to the sum of the resistances" normally existing on the curve, simply because "the *force* applied to (the second car from the rear) in its own direction must be equal to (its own) resistance *plus* the resistance of the rear car multiplied by the secant of the angle between their directions." *Force, i. e.*, statical stress, is one thing; *resistance, i. e.*, destruction of dynamic energy, is another and quite a different thing. We cannot reason away energy with a parallelo-

gram of forces, but most prove where and how, if at all, it is lost by additional friction. As a matter of fact, if the reasoning given below be correct, Mr. Searles' statement is not even true of the statical tension upon the draw-bars; but whether this be so or not, the tension on draw-gear constitutes the mere vehicle for transmitting the power developed by the locomotive to the points where frictional resistances are to be overcome, and it is needless to say that no mere losses of *moment* from obliquity of traction, or from unfavorable leverage, or any detail whatever in a machine of any kind for the transmission of power from its source to its point of application, can either add or take away a single foot-pound of energy. It is, no doubt, entirely pertinent to prove, (1) that obliquity of traction disturbs the direct transmission of power, by producing lateral resultants and otherwise, *and* (2) that additional frictional resistances are thereby caused which increase the demand upon the locomotive, or foot-pounds of work required per foot passed over by the train. But to assume such loss on the first ground only, without proving the second, is simply begging the question. It is taking for granted not only what has not been proved, but what in all probability cannot be proved; for it is all but certain that the centripetal force caused by obliquity of traction is, so far as it has any effect at all, an advantage. For there is a force far exceeding the centrifugal force at highest working speeds, which tends to crowd and does crowd the slowest moving trains against the outside rail, however high the elevation; causing rapid flange-wear of the outside rail and wholly preventing flange-wear of the inner rails. This force is the tendency of all rectangular wheel-bases, whether the wheels be coned or not, to roll in or near to a straight line; the truck being caused to follow the curve by a strong centripetal flange-pressure. In so far, therefore, as the lateral resultant at the coupling points amounts to anything (comparatively it is a mere trifle), it must, as stated, be an advantage and not a disadvantage.

It is for these reasons not really essential to prove, what nevertheless is believed to be the case, that Mr. Searles' method of analyzing the statical strains at the coupling points is not sound.

In the figure let the lines *O O P* represent the axes of two successive cars moving in either direction; *P P*, the two coupling-pins, and *L* the coupling-link. Let the lines *S* represent in magnitude and direction the tensile force acting upon the link and tending to rupture it. As a matter of course, these forces *S* are equal to each other, and it would be in-

teresting to see by what process they could be resolved into forces acting along the axes of the cars without making the latter also equal. As a matter of fact, it is thought to be perfectly clear from the above that



they are so equal. The losses of tensile force from car to car occur *at the centre-pins O* of each car, and not at the coupling-points *P*. The tension on the front end and the back end of the draw-gear *of any given car* is always different by the amount of the frictional resistances of that car; but the longitudinal strains, parallel with the respective axes of the cars, on the rear of the draw-gear of a forward car and the front end of the draw-gear of a rear car, are always equal to each other in magnitude, although different in direction by the amount of the angle between the axes. That is to say, the diminution of tensile force from car to car is *internal* to each car and not at all at the coupling-point. Thus, any reasoning based on the assumption of such loss of tensile force at coupling-points must fall to the ground; since in no sense whatever is it true that "we experience a loss of force due to the angle existing between the cars on a curve," whether the word "force" be taken to mean dynamic energy in foot-pounds, as it should and must mean to prove an increase in curve-resistance according to Mr. Searles' discussion, or simply as another term for tension on the draw-gear.

WM. H. SEARLES.—It is not now necessary to prove that a force acting at an angle with the direction of motion of the body which it moves, acts at a disadvantage. Each car is constrained in its direction by the track, and the car ahead of it on a curve must transmit more force to keep up uniform motion than if the traction was exerted in the line of the rear car. Granted that the resistance is applied at the centre pins of the trucks. Then the car must overcome those resistances while moving in its *own direction.* The moving force is derived from another car moving in another direction, and to overcome the same resistance it must be greater as the angle is greater. The effect of the "lateral re-

sultant" has not been taken into consideration by me for the reason stated by Mr. Wellington, that "comparatively it is a mere trifle." The discussion might have considered each truck instead of each car, but I could not see that this more minute analysis would have any special advantage.

The illustration of the coupling-pins does not affect the case. As given, it is simply the case of a chain of links lying at rest on the surface of a movable pulley. But each car is an independent vehicle, having its own direction and developing its own resistance; hence the view I have taken seems to be correct—and there is a loss of tractive force at the coupling-point exactly equal to what is required to produce the lateral resultant.

There may be cases where any reduction of grade for curvature is a disadvantage. In the case of a coal road, on which the loaded trains are hauled down grade, I am informed that the sudden increase of resistance due to a curve, when the brakes are set at the rear of the train, sometimes has the effect to break a train of coal cars in two. The advantage to the empty trains going up grades equated for curvature, is quite overbalanced by the liability to such an accident.

A. M. Wellington.—I am unable to perceive that Mr. Searles' addition to his discussion has done more than to intensify, perhaps, the original difficulty, as seems clear from his opening sentence. *As respects any static stress*, it is, of course, "not now (or at any time) necessary to prove that a force acting at an angle with the direction of motion of the body which it moves acts at a disadvantage," but that it is "not necessary to prove," before taking it for granted without proof, that there is an actual dissipation of the energy of a prime mover on account of "angles in the direction of motion of the bodies which it moves," seems a curious proposition, in view of the incessant and innumerable changes, both in the magnitude and direction of static forces, which are produced in handling power through almost every form of mechanism. It may be further added that whether the illustration of the coupling-pins is or is not "simply the case of a chain of links lying at rest on the surface of a movable pulley," hardly seems a pertinent fact to adduce as an answer to a discussion; the point being rather to show, not what the diagram is or is not, but whether it correctly represents and discusses the forces actually acting in the given case, and if not, why not. That the addendum does, however, correctly describe what the diagram is, may

be admitted, since the transmission of force from car to car through a train on a curve is, in fact, I conceive, a precise mechanical parallel to the transmission of power by a rope or chain over a pulley; the rope being the string of car bodies, and the car wheels the pulleys. The fact that the pulleys are carried by the rope itself, instead of in a block exterior to it, is a mere detail not affecting the mechanical conditions. In either case the loss from such transmission is simply the friction of the pulley. Conceive a chain made of successive links, each carrying a pulley wheel and being dragged over a large cylinder, or succession of cylinders, large or small. Conceive, further, the rope to be so long and the friction of the pulleys so great that the whole power of the prime mover is consumed in keeping the chain in motion at uniform speed. We have here, I submit, a perfect mechanical parallel to a train in motion on a curve, the only difference being that the resultant of all the forces acting on the wheels does not, in case of a railroad train, lie exactly (although it does nearly) in the plane of the wheels themselves, whereas in the case of the pulley wheels it does. But wherein any "resistance" arises at the coupling-points from "change of direction," or obliquity of traction, or from any other source than the friction of the pulleys proper, seems not only difficult to see, but an evident impossibility. It is, of course, true that the resistances of the rear pulleys would tend to press each pulley in advance more tightly against the surface, and so produce greater friction *in the pulley itself* than would otherwise exist; and similarly in the case of a railroad train it is entirely pertinent to prove that a lateral centripetal force is produced by obliquity of traction, so that the resultant of all forces does not lie in the plane of the wheel, *and* that this fact produces greater friction. The latter, however—the only possibility pertinent to discuss—Mr. Searles himself states, is so trifling a cause for friction that he did not deem it necessary to even consider it; and, for reasons already adduced, it seems probable that in so far as it has any effect it is a beneficial one, tending to reduce the grinding flange-wear which is *exclusively* confined to the outside rail.

Charles E. Emery, M. Am. Soc. C. E.—The able and elaborate discussions of Messrs. Searles and Wellington show their earnest convictions with reference to their particular views. Having been invited to join the discussion, I find I cannot agree with both of the gentlemen, but I will attempt to point out briefly the error of Mr. Searles' position in a somewhat different manner from that employed by Mr. Wellington.

Mr. Searles assumes that the angle between the cars on a curve increases directly the tractive forces, whereas, in fact, such angles merely modify the friction and thereby affect the tractive forces in at least a secondary degree.

The connecting rod of an engine, if five times the length of the crank, brings at times a lateral strain on the guides of 20 per cent. of the effective pressure on piston; but 20 per cent. of the pressure is not lost —only the friction caused by the 20 per cent., or, say, on oiled surfaces, 2 per cent. of 20 per cent., or $\frac{4}{10}$ of 1 per cent., and this much only momentarily at two points in the revolution. So in the train of cars the *tractive* forces are *not* increased from the rear as the *secants* of the angles between the cars; but the traction simply produces centripetal forces measured by the *tangents* of the angles named, which act almost precisely like the super-elevation of the outer rail, and which, therefore, under certain conditions, and perhaps in portions of the length of every train, actually *diminish* instead of increasing the tractive force, but which, when super-elevation is already sufficient, may cause a slight increase of pressure and consequently of friction on the *inner* rail. Mr. Searles acknowledges that Mr. Wellington is right in stating that the effect of the lateral resultant is "comparatively a mere trifle." If so, when it is considered that this lateral resultant is all that causes the resistance discussed, and merely modifies but does not always increase the friction, cannot the supposed losses so elaborately urged by Mr. Searles be called not "comparatively a mere trifle," but really insignificant?

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THE HEAVY GUN QUESTION.

By CAPTAIN O. E. MICHAELIS, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE 10TH, 1884.

Do we require heavy guns? This appears to be the first phase to be examined. My presenting it may excite a smile, and yet the strange apathy of Congress in regard to this matter, during the past twenty years, renders justifiable the assumption that the answer to the question is not so simple as might be supposed. Our Atlantic, Pacific and Gulf coasts, our Lake littoral, all dotted with the great cities of our country, are to-day almost utterly defenseless.

In case of sudden war, can we hope for a *Deus ex machina* in the shape of another *Monitor?* Is it judicious to depend entirely upon the negative defense of a torpedo system? Though it be the best in the world, a determined enemy could yet, by the sacrifice of a portion of his fleet, lay our richest harbors under contribution. Assuredly we require positive protection—heavy guns. According to the reports of the Chiefs of the Engineer and Ordnance Corps, over four thousand guns of position are

needed for existing fortifications. Of course, in time, with the growth of the country, this number will rapidly increase. It may be contended that defensive preparations are unnecessary; that our status as a great nation is so well assured, our geographical position so favorable, that we are safe from attack of any kind. Let us not be lulled into false security; causes for international differences may arise any day; it is needless to indicate them to intelligent readers and thinkers.

A great nation should be unmistakably recognized as willing and able to defend and maintain the privileges and rights of her citizens. Although to-day the wealthiest country in the world, we are far from being in a "touch-me-if-you-dare" condition; this would require time, and years ago General Benét tersely said: "In the modern quick and decisive settlement of differences by the arbitrament of arms, there is not time for preparation after the declaration of war; and a nation may sink beneath the powerful blows of a well-armed adversary in less time than it takes to make a single gun."

> "It is most meet we arm us 'gainst the foe;
> For peace itself should not so dull a kingdom
> (Though war, nor no known quarrel, were in question)
> But that defenses, musters, preparations,
> Should be maintained, assembled and collected,
> As were a war in expectation."

Granting the need of heavy guns, the natural question is—why haven't we them? The answer may be given in bank phraseology—no funds. This want of the sinews of war has borne baneful fruit; it has resulted, objectively, in our present defenseless condition; subjectively, in making us imitators, by depriving us of the opportunity of exercising our inventive faculties.

Those professionally interested in the problem, lacking home chances, have admiringly absorbed European methods, until, to-day, everything stamped with an English or French *imprimatur* is of itself acceptable to us. This mental phase has gone so far that we are in danger of becoming servile; we shrink from carrying out purely American ideas, unless they have been examined and approved by sagacious foreigners. Six years ago, the *Army and Navy Journal*, speaking editorially on the subject of chambered guns, an old American idea in a new European dress, said: "It is rather startling to see the skill of one nation so deftly

appropriated by others, and the first nation neither keeping the skill within its own territory nor apparently caring to keep pace with modern progress. There need be no foreign military *attachés* at Washington, because our inventors seem to get away as fast as possible and sell everything valuable to foreign governments.

Those familiar with the subject know, and everybody ought to know, that if the United States Government wants these chambered guns, or any better guns, it need only appropriate the money and order them of existing American works. These works could now make 100-ton guns if they had the order. * * * * * Let the Government decide on the guns which are the best every way, and find out how to build them for the least money. The decision need not take long with the materials at hand, but if it isn't made soon everything American will be brought back to us with a foreign name. Our mammoth powder will become 'pebble,' and perforated cake be known as 'prismatic,' our pressure gauge as a 'crusher gauge,' and the Hotchkiss case shot be credited to Col. Boxer. Prof. Treadwell's system of gun construction of 1840 is known as Armstrong's of 1856; but no one has seen Armstrong's patent for it. Krupp has appropriated the Broadwell system bodily, and Eastman's slotted screw-breech plug is known as the French breech-loading gun. Mr. S. B. Dean invented a method of mandrelling bronze guns by which strength and hardness are greatly increased, and two years after his patents were taken in Austria, his gun was brought there as the Uchatius gun, and a vast achievement. Their whole artillery is armed with it. The Russian Government built a great foundry at Perm to carry out Rodman's designs on a large scale, and took his powder and his experience along. Mr. Parsons has shown how the strongest guns may be made with steel tubes and cast-iron exteriors. Mr. Hotchkiss has gone to France and established a large factory near Paris, where he has very extensive orders, and has become, in his line, the main reliance of the French Government."

The latest example of the effect of twenty years' stagnation upon the brightest minds, of the results of enforced study rather than opportune experiment, is shown in the report of the Gun Foundry Board, to be examined later.

Not long ago we led the world in armament. We had Rodman, Dahlgren and Parrott ordnance, Colt's revolvers, Gatling guns, breech-loading rifles, and Ericcson monitors. Rodman, by a judicious admix-

ture of ores, a special furnace treatment, and a novel system of casting, had given the world a new product—American gun iron, with a tensile strength of nearly 40 000 pounds. Boston, Reading and Pittsburgh fabricated 25-ton guns that had no peers. At Cold Spring that noble patriot, Parrott, produced an effective, inexpensive rifle that fell not behind the best. At the Fort Pitt Foundry 100 tons of metal were melted, and the monster 1 000-pounder 20-inch gun was presented to the world. Rodman had made the construction of all heavy guns a possibility by his discovery of slow-burning powder. It is needless to go into further details; this is enough to justify the question—what ought to be done to enable us to resume our chiefship in ordnance construction? It is proper, first, to consider the latest proposed official remedy, submitted by the President to Congress in the following letter:

"*To the Senate and House of Representatives:*

I transmit herewith to the House of Representatives the report of a Board of Army and Navy Officers, appointed by me in accordance with the Act of Congress approved March 3, 1883—

For the purpose of examining and reporting to Congress which of the navy-yards or arsenals owned by the Government has the best location and is best adapted for the establishment of a Government foundry, or what other method, if any, should be adopted for the manufacture of heavy ordnance adapted to modern warfare, for the use of the army and navy of the United States; the cost of all buildings, tools, and implements necessary to be used in the manufacture thereof, including the cost of a steam-hammer or apparatus of sufficient size for the manufacture of the heaviest guns.

CHESTER A. ARTHUR.

EXECUTIVE MANSION,

February 18, 1884."

The report of the Board opens as follows:

"The Act of Congress, approved March 3, 1883, under which the Gun Foundry Board was organized, calls for a report on the following points:

1st. Which of the navy-yards or arsenals owned by the Government has the best location, and is best adapted for the establishment of a Government foundry.

2d. What other method, if any, should be adopted for the manufacture of heavy ordnance adapted to modern warfare, for the use of the army and navy of the United States.

3d. The cost of all buildings, tools, and implements necessary to be used in the manufacture thereof, including the cost of a steam-hammer or apparatus of sufficient size for the manufacture of the heaviest guns.

The first question presupposes the establishment of a Government Gun Foundry, properly so called, the establishment to be under the absolute control of the Government, and the details of all work to be supervised and directed by Government officers.

The answer to this question involves simply an expression of opinion as to the superior adaptability, for the purposes of a gun foundry, of any navy-yard or arsenal now owned by the Government.

The second question imposes no limitation, and calls upon the Board to suggest 'any other method' (apart from a Government foundry, pure and simple) by which the purposes of the Act of Congress can be achieved. The Board is evidently called upon to consider the subject of joint action between the Government and private parties for the accomplishment of a national purpose.

The Board decided that there were three points of view from which this subject should be considered, viz.:

1st. That the Government should supplement the plants of some of the steel workers of the country with such additional tools and implements as would enable them to turn out finished steel cannon.

2d. That the Government should give contracts of sufficient magnitude to enable the steel workers of the country to supply the finished guns without its direct aid.

3d. That the Government should establish on its own territory a plant for the fabrication of cannon, and should contract with private parties to such amounts as would enable them to supply from the private industries of the country the forged and tempered material.

The course of the investigation being thus indicated, the Board addressed circular letters to several of the steel manufacturers in the country and to the two companies employed in the fabrication of cannon. These letters and the replies thereto will be found in the correspondence attached to the record of proceedings of the Board, and copies are appended to this report. The replies were unsatisfactory, the subject being a new one to the parties addressed. The expense to be incurred

could not be calculated upon any known basis, and the Board was unable to satisfy the calls made upon it for further information as to the number of guns required, or the probable extent and cost of a plant for the manufacture of such heavy guns as the Act of Congress contemplated.

It was evident that none of the desired information could be obtained from our manufacturers, because of their lack of experience on this subject. It was known, too, that several of the European Governments had had more or less experience of joint action with private artillery establishments. The call by the Act of Congress for 'the cost of all buildings, tools and implements for the manufacture of the heaviest guns' could only be answered by information and experience obtained from abroad, as no such tools or implements have been manufactured or are in use in the United States. The steam-hammer mentioned in the act was recognized as a subject requiring careful consideration. It is coupled with a qualification 'or apparatus of sufficient size,' which indicates that there existed a doubt as to the propriety of the use of a steam-hammer for forging, if other 'apparatus of sufficient size' could be made more efficient. The advances made of late years in the process of forging by compression made this a very important matter for consideration. This subject is necessarily connected with that of the manufacture of the metal to be forged, and involves a study of the recent developments in steel. The actual condition of the armaments abroad, so far as it illustrates the latest ideas, was felt by the Board to be an important part of the information on which it should report, as the character of the new constructions of cannon would necessarily control that of the tools to be recommended for use in their fabrication. The foregoing reasons governed the Board in its decision to represent the necessity of seeking information abroad. Orders were issued, and the Board proceeded to Europe." It then gives its observations in England, France and Russia, and epitomizes the question in the United States thus :

"SOURCES FROM WHICH THE ARMAMENT OF THE UNITED STATES IS SUPPLIED.

Previous to and during the civil war the armaments of the United States were supplied from—

The Cold Spring Foundry, West Point, N. Y.

The South Boston Iron Works, Boston, Mass.

The Fort Pitt Foundry, Pittsburgh, Pa.

The Reading Iron Works, Reading, Pa.

The Builders' Iron Foundry, Providence, R. I.

The Phœnix Iron Company, Phœnixville, Pa.

The Ames Manufacturing Company, Chicopee, Mass.

Since the termination of the war the Fort Pitt Foundry has ceased to exist. The South Boston Iron Works Company has manufactured a few experimental guns and, with the West Point Foundry, has executed some small orders of the Government in the conversion of cast-iron smooth-bores into rifle guns by inserting and rifling a coiled wrought-iron tube.

None of the companies mentioned above have ever made steel guns, and virtually the United States is destitute of a source from which such an armament as the age demands can be supplied.

Condition of Steel Manufacture.

With a view to such experiments as their appropriations would justify, the Ordnance Bureaus of the War and Navy Departments have, from time to time, addressed the steel manufacturers of the country on the subject of furnishing steel for cannon, but thus far have met with only a partial success.

The reasons for this will be noticed farther on in this report, but the fact is here stated to emphasize the conclusion that the immense steel works of the United States, from lack of demand for this special material, have not the necessary plant for forging, and are in no condition at present to manufacture steel for cannon in such quantities and in such sizes as are essential for a suitable armament for the country.

Present Condition of the Artillery of the United States.

To recite under this heading the present armament of the country is unnecessary. Before the introduction of rifled cannon and the use of steel as the material for their construction, the United States boasted of her Dahlgren and Rodman cast-iron guns, which were the models for imitation and the standards for comparison of all nations.

While the rest of the world has advanced with the progress of the age, the artillery of the United States has made no step forwards. Its present condition of inferiority is only the natural result of such want of action."

The report continues with an estimate of the "cost of plant for the manufacture of guns," and closes with the following "General Summary"—conclusions upon the three main propositions considered:

"The foregoing presents the chief points of information that have been gained by the investigations of the Board.

As examples of a practical partnership between a government and a private company in working towards a national object, the experiences in England and in Russia are very instructive, and warn against the adoption of such a system. In England, the Government, in addition to paying, during several years, very high prices for articles delivered, was forced to pay £65 000 to close an agreement; while the company, besides the profits on manufacture, came into possession of a complete working plant at a mere nominal valuation.

In Russia, the Government finds itself involved with a stock company, paying excessive prices for what it receives, and discovers no way of relief except by buying up shares and operating the establishment as a Government foundry.

As an example of depending almost entirely on private works, Germany is a perfect instance. ' The works of Mr. Krupp are practically the sole source of supply of the German artillery. In such a case the Government must be the slave of the corporation, and subject to its whims, caprices and conveniences. It needs no argument to show the dependent condition of the Government under such a rule; it might prove a source of the greatest embarrassment. The Board is well informed that some ten or eleven years ago the artillery officers were very restive under this load, and were making strenuous efforts to be relieved from it, but without success. It is hardly to be supposed that time has quieted the feeling of dissatisfaction.

As an example of depending alone on Government works, France was a perfect instance before the Franco-German war. During the period referred to, the Government foundries were the sole source of supply of the armament of the country; the officers charged with the work formed a close corporation; their action was never exposed to the public; their ideas were never subjected to criticism; the ingenuity and inventive talent of the country were ignored and resisted, and no precaution was thought necessary to provide a supply in case of need of re-armament. The result is well known; a great crisis came; the Government works were inadequate to meet the additional demands made upon them, and

the patriotic efforts of private establishments were inadequate to produce all the material that was needed. How entirely France has now altered her system is shown in a previous part of this report; her present practice is theoretically perfect, and it has proved to be practically efficient. Her Government establishments are still retained, but as gun factories simply, in which the parts are machined and assembled; but for foundry work, she depends upon the private industries of the country, and many of these works have found it to their profit to establish gun factories, which supplement the Government factories to a great extent.

The conclusions of the Board on this subject accord with the plain teachings of these historical instances. It accepts the system now pursued in France as the proper standard for imitation, and recommends that, in inaugurating the manufacture of war material in our own country, a conformity as close as circumstances will admit to the plans which have proved so successful in France should be observed.

Having reached this conclusion, the Board is now prepared to dispose of the propositions into which, as stated on the seventh page of this report, the second interrogatory in the Act of Congress was divided. The first proposition was thus presented, viz. :

'That the Government should supplement the plants of some of the steel workers of the country with such additional tools and implements as would enable them to turn out finished steel cannon.'

The adoption of this proposition would involve the Government in the embarrassments which now exist in Russia, and which we have seen were so costly to the English Government in its partnership with the Elswick Ordnance Company.

The Board does not approve of such joint action.

The second proposition was thus presented, viz. :

'That the Government should give contracts of sufficient magnitude to enable the steel workers of the country to supply the finished guns without its direct aid.'

This proposition, if adopted without any qualification, would make the Government dependent entirely upon the private industries of the country, which might combine to the detriment of the public service. The Government would have no guard against extortion, and would be powerless against a combination. An actual instance of such a combination is cited in a previous portion of this report as having taken place in

France, but the independent position of the Government made the effort futile.

The Board does not approve of this proposition taken by itself.

The third proposition was thus presented, viz.:

'That the Government should establish on its own territory a plant for the fabrication of cannon, and should contract with private parties to such amounts as would enable them to supply from the private industries of the country the forged and tempered material.'

This proposition is approved by the Board, and is regarded as the foundation upon which our system of manufacture should be built up. If this be done, and the Government made secure by the possession of works of its own, there is every reason to adopt, in addition, the idea embodied in the second proposition, in order to supplement the Government establishments.

A State, with any pretensions to military power, should provide itself with factory facilities on a sufficient scale to perform the work of establishing standards, making experimental guns and fabricating cannon on a moderate scale; but it is not considered judicious to concentrate in the Government establishments all the work of fabrication, or to include within their operations the preparation of such material as can be provided by the private industries of the country. In the case under consideration, the purchase of the steel required for cannon will stimulate our own manufacturers, and interest them in the operations of the Government. The Board is thus led to the conclusion that it is not advisable to embark in the establishment of a gun foundry, properly so called, but that it is more judicious to establish gun factories, and to purchase the material from our manufacturers."

As confirming my previous statement, I invite especial attention to the following "conclusions" of the Board:

"It accepts the system now pursued in France as the proper standard for *imitation*, and recommends that, in inaugurating the manufacture of war material in our own country, a conformity as close as circumstances will admit to the plans which have proved so successful in France should be observed."

Certainly, the main conclusions of the Board can be fairly refuted by our own experience, since we did, thanks to the native inventive genius, produce guns which, in the language of the Board, "were the models for imitation and the standards for comparison of all nations."

First, then, as to the "conclusion" relative to the supplementing of private plants by Government, Mr. Charles Knap, whose name shines in a galaxy including Alger, Wade, Bomford, Dahlgren, Rodman, and Parrott, writes, under date of May 6th, 1884:

"My arrangement with the Government for the fabrication of the first gun of the 15-inch class, and for the first gun of the 20-inch class, was, that I contributed, free of charge, all the then existing facilities possessed by the Fort Pitt Foundry; that I proceeded to acquire such further facilities as I deemed necessary for the work in hand; that an ordnance officer should keep an account of the labor and material expended in these preparations, and also of the labor and material expended in the fabrication of each gun. The aggregate amount of these actual outlays was to be reimbursed to me, and the Government was to own and possess any portion of the preparations which could be removed. Eventually I became the owner of the entire plant, by purchase at the cost price, as exhibited by the statement of the supervising officer."

Secondly, as to the "conclusion" relative to the giving of contracts to private manufacturers. Our war, than which no better opportunity for the manifestation of the cupidity dreaded by the Board—a spook of its own creation—can be imagined, demonstrates the narrowness of its judgment of the calibre of our people. We were involved in the greatest conflict of the age, had immediate and constant need of patented ordnance fabrications, and yet no instance can be cited where the Government was compelled to "guard against extortion," or was subjected to the "whims, caprices, and conveniences" of a corporation. We had, during the war, three great gun plants—the South Boston, West Point, and Fort Pitt foundries. Listen to their record during the struggle:

Metcalf, now one of our leading steel authorities, then at Fort Pitt foundry, of whom Mr. Knap writes, "if you have exhausted Mr. William Metcalf's recollections, you must be pretty well loaded, for he was an ambitious and attentive witness of all that went on at the foundry," says: "In regard to regulating the price [to be paid by Government for guns], I remember distinctly how it was done during the war, when prices were rising so rapidly. The Ordnance Department several times sent commissions of officers to the foundries; when they came to Fort Pitt they were referred to me. I gave them the

books and showed them the contract prices for iron, fuel, and supplies; the wages lists and other items of expense ; from these we made up the cost of guns and projectiles, added 20 per cent. for contingencies and profit, and so fixed the prices. I do not know how the Government could get any more reasonable basis than this ; we certainly made good guns, and as cheap as Government could have done it."

Of Parrott, let the West Point necrology speak: "Long and careful study of the subject of ordnance, to which he had given especial attention when in the army, had enabled his natural genius to invent, and prolonged and costly experiments to perfect, a system of rifled cannon and projectiles, so simple, effective and inexpensive that from the first commencement of hostilities it was adopted by the United States Government for the use of its armies and navies. At the first battle of Bull Run the guns called by his name hurled their unerring missiles at his country's foes, and at every succeeding engagement on land or water during the continuance of the stupendous war the 'Parrott' cannon thundered and the 'Parrott' shell flew screaming on their destructive course, doing their steady duty in honorable representation of their inventor, who thus regretted that he was unable to be in the field to do it in person: 'If I were a younger man (he said) I should return to the army and do what I could to aid my country there; but at my age, and in my position, I am denied the opportunity of helping the Government in that way. But in this way I can be of use, and I intend that these guns shall cost the United States no more than is absolutely necessary.' This remark was called forth by the remonstrance made to him that the prices he had fixed for his cannon, &c., were unnecessarily low; that he would receive no credit from any one for his moderation; that the Government must purchase all that he could manufacture on his own terms (as was indeed the case), and that here was the opportunity, which could never occur again, to acquire enormous wealth. Smiling in the quiet way habitual to him, he replied that he had no desire to possess extraordinary riches, and that he would rather not acquire them in that way; and then, with earnest seriousness, he spoke as has been quoted. As he had spoken, so he did." I avail myself of this opportunity to quote a tribute to this manufacturer of patent guns and projectiles in war times from one who knew him well, and who writes May 5th, 1884: "He could, without doubt, have made three times as much money, as he had the monopoly of rifled guns and projectiles, and it was only the immense

amount of business that enabled him to make a very moderate profit. He was the most patriotic, disinterested man I have ever known, yet he never received the slightest expression of appreciation of his conduct from the Government or the public, and he carried his generosity to his country much farther than he should have done, in view of the interests of his associates and relatives, as well as those of the West Point Foundry."

"The South Boston Iron Company," writes one who has been intimately associated with it for many years, "filled large orders for heavy guns at prices based upon iron at 40 dollars per ton, when the pig iron would have sold in the market at a much higher price, even going as high as 110 dollars per ton at one time, and at no time did the Government pay higher than 60 dollars per ton." Twelve years after the war, this company received from the Chief of Ordnance, with the cordial concurrence of the Secretary of War, the following "character:"

"The South Boston Iron Company, at first Cyrus Alger, and later Cyrus Alger & Company, has done work for this Department, manufacturing heavy and light guns and projectiles, at various times since the year 1828, and, it is believed, always to the entire satisfaction of the Government. Within the last fifteen years the firm has delivered, among other deliveries, 272 Rodman guns, of which 103 were 15-inch, weighing about 50 000 pounds each. The iron the firm uses in its manufactures is known to be of the best for gun construction; and the perfection of the finished products has always received the highest commendation."

Thirdly, as to the "conclusion" relative to the Government's establishing, on its own territory, a plant for the fabrication of cannon, and its contracting with private parties for what may be called the raw material. There is no need of discussing this "conclusion," as it is based upon the Board's disbelief in the efficacy and reliability of the two other methods considered—disproved, as I have shown, by American precedents.

I have given in brief our own experience. I will cite, in further refutation of the second conclusion, the experience of Germany, whose ordnance condition should be, from the Board's view-point, as deplorable as our own. The Board says: "As an example of depending almost entirely on private works, Germany is a perfect instance. The works of Mr. Krupp are practically the sole source of supply of the German artillery. In such a case, the Government must be the slave of the corporation, and subject to its whims, caprices and conveniences. It needs no argument to show the dependent condition of the Government under

such a rule; it might prove a source of the greatest embarrassment. The Board is well informed that some ten or eleven years ago the artillery officers were very restive under this load, and were making strenuous efforts to be relieved from it, but without success. It is hardly to be supposed that time has quieted the feeling of dissatisfaction." Mr. J. S. Potter, our consul at Crefeld, who recently visited Essen, reports to the Secretary of State (see United States Consular Reports, No. 38, February, 1884 :)

"GOVERNMENT ORDNANCE ESTABLISHMENT AND PRIVATE ENTERPRISE.

Mr. Krupp's is the largest gun foundry in the world, being much more extensive and complete than the Government establishment of England, at Woolwich. It is able to complete each year from 3 000 to 4 000 field and mountain guns, 500 siege, fortress, naval, and coast guns, of light calibre, and 100 heavy naval and coast guns.

The full productive capacity of Krupp's establishment is never placed at the disposal of any one state or government, as large undertakings for governments in different parts of the world are always in process of execution. It is by reason of this condition that Krupp's establishment has reached its present enormous proportions, and is yearly increasing.

An establishment for the manufacture of ordnance which is maintained and operated by a State for its sole use, will sometimes be fully occupied, and at other times have very little to do. The sources for a profitable or paying existence would in such case be wanting, unless articles for peaceable purposes and the open market were manufactured. The Imperial Government of Germany, which has completely mastered the science of economy in governmental matters, and whose ordnance department and equipments for war are the most advanced and perfect in the world, does not maintain a national manufactory for the production of cast-steel ordnance. The Government prefers to purchase war materials of this description from Mr. Krupp, or other private manufacturers. To keep such an establishment occupied, the State would, in times of peace, produce beyond its needs, and the products of many years of manufacture would accumulate. And it is not forgotten that the ideas which generally govern such national establishments are those of engineers who move in official ruts, and that when war does come the accumulated ordnance would most likely be found deficient in the

modifications and improvements which had in the meantime been introduced by the unfettered and more enterprising ingenuity of private manufacturers.

Germany, therefore, regards it as to her advantage to patronize Krupp, and to see that no obstacles are allowed to exist which will in any way interfere with his engagements with other nations. In this way there is maintained within the jurisdiction of the empire, and without cost to the state, the largest and most progressive establishment in the world for the manufacture of war material, and which has a force always large enough to meet any demands which the Government can make upon it in time of need.

Even at the private establishment of Krupp, which is doing business for nearly all the states of the world, the orders in hand for war material are not always in proportion to the power of production. But he provides against fluctuations in the character and number of the force he employs by manufacturing 'peace materials,' such as railway plant, wheels, locomotive tires, shafts, and other heavy parts of machinery for steamships, also bridges, &c.; so that, in the event of a lull in the demand for war material, he has steady occupation for the trained force of workmen attached to his works."

The plan proposed by the Board of Government gun factories would be open to the same objections which it advances against dependence upon private enterprise. The appearance of its phantom is but postponed. The steel manufacturers (there would be but few plants able to supply the enormous ingots required) could as easily combine as the gun makers. The Board says: "It would not be necessary for the Government to be associated with a large number of firms for the supply of its material, for it is probable that the private establishments that would take up the subject would only be those with large available funds, which they would be willing to put in a special plant, and for remuneration on which they would be willing to wait a reasonable time." He little knows the temper of our people, who would seriously suggest that in the event of such a combination we could import our steel. A Congress that enacted that the American flag should be made of American bunting, would not hesitate to direct that American guns should be made of American metal.

The Board appears to have been particularly impressed with General Dard's marine gun factory at Ruelle, of which it reports:

"At the 'Fonderie à Ruelle' all the constructive force of the marine artillery has been concentrated, and here all the largest guns are made. It contains the most remarkable collection of tools of the age. They are designed for guns of 34 centimeters and upwards, and have a capacity for handling guns of 160 tons in weight and 60 feet in length. The shop in which these tools are placed is about 450 feet in length and 131 feet in width, having a height of 85 feet at the central peak of the roof. At one end is the tubage pit, in which the gun tube is placed upright to receive the hoops. The bottom of this pit is at a depth of 85 feet below the floor. It is excavated in a rectangular form, and is divided into four stories, contracting in area as the lower level is reached; at each story or landing-place, the opening can be floored over to accommodate the work of hooping any length of tube. The heating furnaces are on the first story below the floor. The tools already in place are the following, but there is room for fully a dozen more of a similar character:

Two turning lathes, capable of turning guns 15 meters long. These can be increased in length 10 meters.

Three boring machines for same.

One rifling machine for same.

Two smaller boring machines, with adjustable connections for turning.

Two other machines for performing all the details of the work about the breech, for receiving the fermeture, turning the screw, slotting, piercing holes, &c.

Two movable cranes, one of 100 tons, the other of 30 tons capacity."

The South Boston Iron Company have two 150-ton lathes, each capable of turning guns 60 feet in length, and a dozen of somewhat smaller capacity; they can to-day turn out more heavy guns in a given time than can the Ruelle works. (The main resources of the West Point Foundry and the South Boston Iron Company are given in the Appendix.)

I have regretfully come to the conclusion that the report of the Foundry Board holds out little hope, even if its views be carried out, of enabling us to regain our superiority; and this, I think, is due to the fact that it appears to have confined its attention exclusively to the built-up forged steel gun—an impracticable construction here for years to come, a construction uncertain if practicable, unnecessary if certain and practicable.

A critic, to be consistent, must suggest a proper remedy. What, then, should be done to restore to us our ordnance position among nations? It is

very certain that, whatever new and adequate constructions may be undertaken, years must elapse before they can be produced in numbers sufficient for our wants. We have an enormous seaboard to arm. Fortunately, Duilios are few in number, and attacking fleets must be made up in great part of vessels vulnerable by what may be called second-class guns. Our first effort should be directed to the utilization, in the light of the best modern experience, of the means at hand. We still retain the art of making the finest cast-iron guns in the world, and there are still those who believe that their usefulness is not entirely gone. Twelve years ago, I addressed to the Board on Heavy Rifled Ordnance, instituted under the Act of June 6th, 1872, a letter which closed as follows: "It seems to me that it would be worth while, provided cast-iron is not entirely superseded as material for the construction of rifled ordnance, to construct a gun on the Swedish plan, ringed or 'fretted' with Krupp, Bessemer or other steel, or perhaps with the homogeneous metal obtained by the Martin-Siemens process." All our magnificent smooth bores can be converted into very effective rifles by the adoption of this plan. The West Point and South Boston foundries, to whom Government owes a great debt of gratitude, could thus be profitably employed for years.

These guns would, however, be at best but acceptable makeshifts. We must take immediate steps for the creation of the great American gun of the future. Of what shall it be made, and how? Open-hearth steel, hollow-cast, cooled and annealed from the interior. The lamented Holley, who had no peer as a modern steel expert, writes, in 1878, as follows:

"The most remarkable of the several revolutionary developments of the steel manufacture during the last few years is undoubtedly the production, at Terre-Noire, in France, of solid castings, without blow-holes, in malleable steel—castings which, after no other treatment than annealing, have the strength, specific gravity and physical qualities generally of forged steel. The harder variety, in the shape of shells, goes without breaking through armor plates which injure chilled-iron shells, and even hammered steel shells, in a greater degree, and the softer varieties bend double cold and stretch 25 per cent. and more in tension, like rolled steel boiler plates. * * * * * * The Sheffield and Krupp castings are melted in crucibles; they are very hard, and in spite of the long annealing they usually undergo, they show but little ductility and toughness. The Terre-Noire metal, on the other hand, is produced cheaply in the Siemens furnace, and possesses, in the cast state, all the necessary

qualities for industrial and structural purposes. It is soft and malleable, and as strong as ordinary steel of the same grade is after rolling or hammering, and, strange to say, its density is always as high and sometimes higher than that of ordinary forged steel. These statements, startling as they may be, are supported by facts developed in numerous experiments made by the Terre-Noire engineers in developing the manufacture, and by the French Government in testing it."

Lieutenant E. W. Very, U. S. N., in his prize essay on "The Development of Armor for Naval Use," writes, in 1883, of the Terre-Noire process:

"This method has for its main object the elimination of blow-holes, and it accomplishes it in a manner which certainly appears more rational than the Whitworth process, in that it aims to prevent the formation of gas in the metal by the use of silicide of manganese. The silicon prevents blow-holes by decomposing the oxide of carbon, which is in dissolution and tends to escape during solidification. The manganese reduces the oxide of iron and prevents a further production of gases by the reaction of the oxide on the carbon. In the decomposition of oxide of carbon by silicon, silica was produced, and afterwards a silicate of iron, which remained in the steel, interposed between the molecules preventing cohesion, which would be as bad for the metal as the blow-holes themselves; but the manganese allowed the formation of a silicate of iron and manganese, which is more fusible, and passes into the slag which floats on the metal. In this way the metal is not altered.

Euverte's conclusions from results obtained at Terre-Noire are stated as follows: 1st. Steel derives the whole of its physical properties from its chemical composition and molecular state. 2d. Mechanical operations, such as forging and rolling, are not necessary to the production of the best results as to quality, and steel which has been cast without blow-holes in a suitable manner and reheated and tempered in the right way attains a perfectly satisfactory molecular state, which makes it applicable for all purposes. This may seem paradoxical at first sight, but numberless experiments have given results which seemed to be guided by an immutable law."

Mr. E. B. Dorsey, M. Am. Soc. C. E., has been kind enough to write out for me his observations on the latest open-hearth practice:

"What is known commercially as open-hearth steel is made by the Siemens-Martin process in a reverberatory furnace heated by gas made in the usual Siemens regenerative furnace.

The following is the process adopted by one of the largest works in the world:

For example, suppose the furnace to have 15 tons capacity, it is charged somewhat as follows, the quantities varying with the chemical composition of each ingredient:

10 tons of pig iron.

2½ " " scrap steel.

After this is thoroughly melted, add from 1 to 2 tons of pure hematite ore; the oxide of this, uniting with the carbon of the cast-iron, causes active ebullition, or boiling; when this subsides a specimen is taken and tried physically; if this comes up to the requirements it is tested chemically; if this is correct the charge is run off into ingots; samples being taken at the beginning, middle and end of each run. If the tests, physical or chemical, are not up to the requirements, more ingredients are added. If it has too much carbon, too great tensile strength or too little ductility, hematite ore is added; if it has too little carbon, too little strength or too much ductility, more pig iron is added. After each addition it is tested, and when correct is run off as above.

The great advantage of this system over the Bessemer is that there is plenty of time to make the chemical and physical tests, and correct every imperfection, before the charge is run off.

As the chemical composition of each ingredient is known, by using similar or proportionate quantities, it is easy to get perfectly uniform charges in composition and character in any given number of charges.

The perfect uniformity in composition and character of this steel makes it so desirable for structural purposes."

The special adaptability of this metal to gun construction lies in the fact of there being "plenty of time to make the chemical and physical tests, and correct every imperfection, before the charge is run off." Holley, whose "Ordnance and Armor" is classic, prophesies of this metal:

"It should appear, judging from the general character of this steel as shown in the final table, added to the results of this gun experiment—which is but one experiment, and hence may not be considered conclusive—that the American system of cheap ordnance—cheap because it is cast—is to be successfully realized. If so, it will follow that the criticism upon the standard American gun, that it is comparatively worthless because it is cast iron, will be reversed. We can hardly conceive a fact of

greater magnitude—from a defensive point of view—than this: that while the United States has at this moment not a single standard type of naval gun, or gun of position, that is comparable in efficiency with the guns of foreign states, it has, by means of the good policy of its Ordnance Department, studied the results of foreign experiments and avoided the enormous cost of original investigations; and that this policy must now be rewarded by the establishment of the cheap cast gun, the metal to be, not crude iron, but steel having three or four times the strength, as made according to the specification detailed in the foregoing pages. And although we have good field guns, the sound-casting system will be equally applicable for this purpose also, in view of its economy.

The protection of the whole coast of the United States (greater than that of any other power) and its entire interior defenses, heretofore quite inadequate as compared with the protection which steel ordnance provides for other countries—this whole problem may now be solved by the perfection of the art of solid-steel casting, if, indeed, this art does not raise the standard while it largely reduces the cost of armament.

In 1865 the cost of heavy guns was as follows:

		Cents per pound.
Armstrong	10.5-inch wrought-iron hoop gun	33.6
Krupp	15-inch solid steel gun	87.5
Blakely	10-inch steel tube, hooped with steel	78.5
Whitworth	7-inch " " "	62.5
Parrott	10-inch cast-iron, hooped with wrought-iron	17.0
Rodman	10-inch cast-iron	9.75
"	15-inch "	13.2

The present cost of guns is largely reduced, but the above relative costs will hold good, and they show the very notable comparative cheapness of the cast gun. The exact cost of solid cast-steel guns cannot yet be exactly estimated, but it is certain that it will not exceed one-third the cost of hammered-steel guns.

With reference to general machinery, it must be obvious that a metal simply cast into usable form, and having the range of tensile strength from 50 to 30 tons per square inch and the corresponding elongation of 7 to 28 per cent., is destined to replace not only iron castings, but iron and steel forgings, which are several times more costly and no stronger.

The hammering of a large mass of steel—for instance, a 40-ton ingot for a gun or a marine shaft—is a very costly and hazardous undertaking. There are but few, if any, hammers in the world which can condense such a mass to the core. The hammer and the special tools are enormously expensive; the new 60-ton hammer plant at Creusôt will have cost half a million dollars. The heating—several days for a single heat—and the loss by oxidization, and the wasters due to cracking from inadequate or over heating, are important elements of cost. Forging under the heaviest hammers reaches only the parts in the immediate vicinity of the impact; the piece is therefore subjected to a series of internal strains, due to the difference in the molecular arrangement of adjacent parts. Even in the finished piece the same difference in molecular structure exists. Each part does not receive exactly the same reduction, and crystallization is not equally changed throughout the mass. It is thus left to internal strains which may cause ruptures when and where least expected.

The casting of a piece which has the desired shape, and requires no reheating beyond a slow annealing, is so great a progress that it must be obvious to all practical men, especially when it is considered that the product possesses, in every part of its homogeneous mass, all the physical qualities of forged steel."

Already ordinary castings in this country have a tensile strength of over 60 000 pounds, and there is not the slightest doubt that with careful manipulation and special methods of casting, possibly under compression, this may be doubled. A member of our Society, who has recently visited Terrenoire, states that we have open-hearth plants fully equal if not superior to the French establishment.

The growth of the industry in this country is shown by the following recapitulation of the net tons of open-hearth steel ingots produced in the decade 1873–1882, furnished by Mr. James M. Swank, Secretary of the American Iron and Steel Association :

1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.
3 500	7 000	9 050	21 490	25 031	36 126	56 290	112 953	146 946	160 542

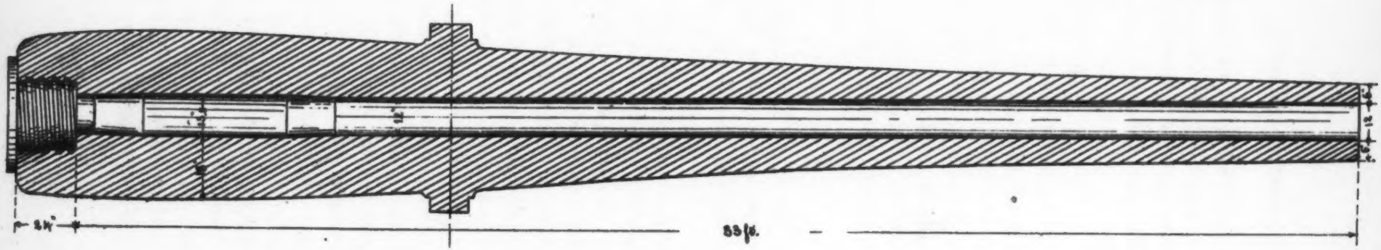
Preparations are now in progress for the making and handling of 40-ton castings. Mr. S. T. Wellman, Superintendent of the Otis Iron and Steel Company, informs me that, if his company were assured Government work for the next ten years at the rate of 500 000 dollars

annually, "they would assume the manufacture of the large guns, to be cast by whatever method might be thought best." He further says: "I am very sure that we can produce a metal good enough for heavy guns without pressure; but, with pressure, we could do as well as Whitworth, who so far has beaten the world." Major L. S. Bent, Superintendent of the Pennsylvania Steel Company, writes: "From our experience with smaller work, I am led to believe that larger castings, for guns, could be made with the regularity, and of the solidity and strength required. Of course, some time might be required to develop fully this new feature in our business, to overcome the difficulties and risks attending the handling of such large masses of steel, and to fulfill all the conditions required." I give Major Bent's letters in the Appendix.

We have thus the cumulated opinions of Holley, Wellman and Bent upon the feasibility of using open-hearth steel for ordnance construction. At the St. Paul convention Mr. William Metcalf, M. Am. Soc. C. E., an accepted authority upon the physical qualities of steel, expressed to me the opinion that a powerful gun, upon the Rodman plan, might be cast from this metal. Since that time I have given attention to the subject, and have arrived at the conclusion that we have, without the establishment of a Government gun foundry, a chance to reassume ordnance leadership, by carrying out a purely American idea—casting from open-hearth steel a Rodman gun, annealed from the interior. I submit a rough sketch of my conception, not ready for immediate practical embodiment, but to be developed by hard study and careful experiment. (Plate XXXII.) Compared with the calculated power of other proposed 12-inch rifles, this model should be able to cope successfully with the heaviest iron-clads. Rodman, by brains and work, made the most powerful guns of the day from cast-iron. Can we not, by the same means, reach the same result with this superior metal?

How can these latent capacities be brought to bear? We have abundance of capital, an ever-ready and growing plant, plenty of ability, but no policy. Fortunately, under our system of government, state policy is shaped by public opinion, and it is for intelligent thinkers to make this felt. The course to be pursued is simple. Let Congress make a standing annual appropriation of two million dollars, and the problem is solved.

PLATE XXXII
TRANS. AM. SOC. CIV. ENG'RS
VOL. XIII NO. CCLXXXIV
MICHAELIS
ON HEAVY GUNS



Sketch of proposed open hearth Steel Gun, 12 in Cal. "hollow cast under compression if feasible or necessary, cooled and annealed from interior." Weight about: 50 tons.

O. E. Michaelis, Capt. of Ordnance. U. S. A.

Frankford Arsenal.
May 1884.

Since the above was written I have ascertained the existence of the following letter, in which General Benét puts the question so clearly and practically that it cannot fail of convincing :

"Ordnance Office, War Department,
Washington, May 8, 1883.

Commodore E. Simpson,
President of Board on Foundry, etc.:

Sir,—Your letter to the Honorable Secretary of War, of the 1st inst., requesting 'that the Chief of Ordnance may be directed to communicate such views and plans as may seem to him best calculated to assist the object in view'—that is, the establishment of a national foundry at a navy-yard or arsenal, or any other method whereby heavy ordnance, adapted to modern warfare, can be manufactured—has been referred to my action.

*　　*　　*　　*　　*

3d. As to any *other method.* * * * The only other method is to assist and encourage some private foundry in establishing the plant necessary for such costly operations as the manufacture of heavy ordnance.

4th. I take it that, whatever plan may be adopted, the final object to be obtained is the production of 100-ton guns. With this in view, the establishment of a national foundry will, in the end, cost many millions of money. A private foundry may be willing to co-operate with the Government, if the latter will provide some of the more costly plant, such as new furnaces, steam-hammers, large lathes, cranes, etc., the foundry to reimburse the Government by paying a certain percentage on all work performed with said plant until the whole cost is repaid. In the course of time—the length depending on the quantity of work annually ordered by the United States—the United States would be entirely reimbursed for the original expenditure, and the foundry become self-sustaining. It is believed that Congress would be more likely to approve of the smaller expenditure ; and the foundry could supplement Government work by outside orders. Such a plan would combine, in a marked degree, and to the advantage of all concerned, private enterprise and activity with the so-called governmental conservatism. If some practical scheme of this sort can be decided upon, I believe it will prove the best for the early production of heavy ordnance. Provision, of course, should be made for the United States

taking possession of the foundry, at any time, by paying the appraised value.

* * * * *

Respectfully, your obedient servant,
(Sgd.) S. V. BENÉT,
Brig.-General, Chief of Ordnance."

I have also received, through the good offices of Dr. R. W. Raymond, from M. A. Pourcel, of Terre-Noire, a copy of his "Notes on the Manufacture of Solid Steel Castings," read before the Iron and Steel Institute, and which may be found in its journal. All interested in the subject should read this paper. From it I learn that, in late years, the main studies at Terre-Noire were directed to two points:

1. The manufacture of large castings.

2. The methods of annealing and tempering to be applied to the metal in order to give it all the mechanical properties corresponding to its chemical condition. The conclusions reached are summarized thus:

"This brief account, written with the diffidence of an author speaking of his own work, if it does not awaken the false idea that the days of the steam-hammer are numbered, at least affirms again the important fact, that steel can acquire all its mechanical properties by other means than by hammering."

In the discussion that followed the reading, Mr. James Riley, of the Steel Company of Scotland, gave an account of some special work done at Hallside: "The heaviest casting they had made was a gun-carriage for an eminent firm, for which they charged 28 tons of steel. This carriage and the two girders used in connection with it—castings of 15 tons each—had been machined on nearly all their sides, and would, he had no doubt, completely satisfy M. Pourcel in the matter of being without blow-holes. Their latest achievement had been the casting of two stern frames for use in the construction of ships of about 2 000 tons gross register. The greatest dimensions were 27 feet by 13 feet, with boss for propeller shaft 2 feet 2 inches diameter. One of them was tested recently in presence of members of Lloyds' committee, and gave great satisfaction." The breaking strain of test specimen was about 70 000 pounds, and the elongation, measured on 8 inches, 14.8 per cent. The composition was C. 0.23, SI. 0.25, MN. 0.8, P. 0.04, and S. 0.03.

APPENDIX.

THE WEST POINT FOUNDRY.—THE SOUTH BOSTON IRON WORKS.—THE PENNSYLVANIA STEEL COMPANY.

THE WEST POINT FOUNDRY.

For general information, especially in regard to the early history and work of the foundry, reference is made to *American Inventions*, by Charles B. Norton, a copy of which is herewith presented by the West Point Foundry Association (the name of the firm was changed in 1883). The information given in this book, p. 362 *et seq.*, was obtained originally from the founders, and may be considered reliable.

Parrott rifled guns, 1861–1865.

The following were manufactured :

10 in.	8 in.	100 pdr.	60 pdr.	30 pdr.	20 pdr.	10 pdr.	3 in.	
47	176	588	132	853	668	347	415	3 226

with about 1 600 000 projectiles (see p. 363 *cit.*).

Year 1866.

In this year the firm had in hand contracts for 117 10-inch smooth-bore Rodman guns, which contracts, however, were canceled by the Government, and none of the guns were completed.

[This action is believed to have been taken pursuant to an act or resolution of Congress stopping all ordnance work, and reference can be made to the proceedings of Congress for that year (1866).]

From 1866 no work of consequence was done for the Government, until the 9-inch Sutcliffe gun was contracted for in 1873.

Brief of principal manufactures for the War and Navy Departments from 1873 to 1883, inclusive:

Breech-loading Rifled Guns.

1 9-inch Sutcliffe rifle.
1 11-inch rifle converted from 15-inch M. L.'s. b. Rodman.
1 8 " " " 10 " " "
12 Parrott rifles " " 100 pdr. Parrott M. L. rifle.
1 " " " 60 " "
1 " " " 30 " "
1 " " " 20 " "
3 3.20-inch chambd. rifles converted from 3-inch M. L. rifle.
1 3.15 " " " 3 " "
2 3 " rifles " " 3 " "
1 3 " Sutcliffe " " 3 " "

Converted Muzzle-loading Rifled Guns.

3 11-inch rifles, converted from 15-in. Rodman wrought-iron tube.
1 9 " " " 10 " " " "
1 9 " " " 10 " " steel tube.
1 8 " " " 10 " " "
17 8 " " " 10 " " wrought-iron tube.
11 8 " " " 11 " Dalhgren " "

Life-saving Guns.

24 3-inch mortars, beds and implements.
200 2½ " smooth-bore bronze life-saving guns, Lyle mod., 1877.

Wrought-iron Tubes.

1 tube for 11-inch B. L. rifle.
5 " " 11 " M. L. "
11 " " 8 " B. L. "
107 " " 8 " M. L. "

Projectiles.								Sabots.		
Butler.	Euresta (arrick).	Hotchkiss.	Parrott.	Reilly.	Sibley.	For 2½-inch Bronze Life-saving Guns.	9'' Sutcliffe.	Butler.	Dard.	Hotchkiss.
5 331	520	380	1 755	20	20	2 400	310	235	6	425

Miscellaneous.

89 wrought-iron loading cranes, 2 field carriages, 1 limber for field carriage.

The present establishment comprises :

1 pattern and carpenter shop.

2 forging and smith shops.

3 iron moulding and casting foundries.

4 brass and bronze foundries.

Finishing shops.

Boiler shop.

The forging and smith shops are especially equipped, as regards ordnance, for the manufacture of coiled wrought-iron gun tubes. The principal accessories for this and other work are :

1 heating furnace for bars.

1 coiling apparatus, with steam crane as an adjunct.

2 large reverberatory heating furnaces for forgings.

1 press furnace for welding tube sections.

5 steam hammers, from one of 8 tons, single acting, to one adapted to light forging, and including one 3 500 pounds, double acting.

Capacity of heaviest crane, 30 tons.

Iron Foundry.

The principal accessories are :

1 reverberatory furnace, capacity 9 tons.

2 reverberatory furnaces, arranged especially for gun castings, with a joint capacity of 35 tons.

2 gun pits, 20 feet deep over all.

2 large cupola furnaces.

Capacity of heaviest crane, 40 to 50 tons.

Brass Foundry.

Especially fitted at present for the casting of 2½-inch smooth-bore bronze life-saving guns, and adapted generally to the casting of bronze and brass pieces of smaller dimensions.

Finishing Shops.

The principal accessories for ordnance work are:

1 lathe, 29 feet length with 7 feet swing.

1	"	27	"	" 6 "
1	"	24	"	" 9 "
4	"	24	"	" 5 "
8	"	40 inches swing.		
3	"	30	"	
4	"	24	"	
6	"	22	"	

6 boring beds, 44 inches swing.

1 planing machine, 28 feet length, fitting with machinery for rifling heavy guns.

7 planing machines, from 5 to 13 feet length.

1 rifling machine for rifled guns.

2 hydraulic presses, fitted for finishing exterior of cylindrical portion of heavy and field projectiles.

Capacity of heaviest crane, 20 tons.

The establishment is capable at present of turning out 100 8-inch coiled wrought-iron tubes-breech-insertion per year, and probably 6 000 8-inch projectiles, without interfering with work to be done for private parties.

The South Boston Iron Works.

Office of
The South Boston Iron Works,
57 Foundry Street, Boston, May 24, 1884.

Captain O. E. Michaelis, U. S. A.,
Philadelphia:

My Dear Sir,—I have been rather embarrassed in deciding just what information you wanted, knowing that you had been here long enough to know our ways and means thoroughly; but since you ask definite questions, I am very ready to answer.

Shops.—We have four distinct machine shops, two blacksmith shops, one boiler shop, two foundries, two pattern shops, one flash shop, sand house, &c.

Machinery.—We have two lathes, 90 feet long, weighing some 150 tons each, capable of finishing guns of 60 feet long and up to 100 tons weight; six mills or lathes for finishing guns up to 30 tons weight; six mills or lathes for finishing guns up to 10 tons weight; twenty lathes for small work and fine finish; one planer that will finish 10 feet square, 30 feet long; six planers of smaller capacity.

Foundry.—We have three reverberatory furnaces of 40 tons capacity each, two do. of 14 tons each, four cupola furnaces of different sizes.

Our establishment covers some six acres, and we have employed 400 men, although our present force is some 250.

I omitted to say we have one traveling crane of 40 tons capacity, one of 18 tons, nine common cranes of capacity from 10 to 40 tons.

We have turned out 25-ton guns (finished weight) at the rate of two per week through the year, and 8-ton guns at the same rate at the same time, and shot and shell at the rate of 30 tons per day.

Yours very respectfully,

WM. P. HUNT.

PENNSYLVANIA STEEL COMPANY.

The Pennsylvania Steel Company,
L. S. Bent, Superintendent,
Steelton, Penn'a, May 6th, 1884.

Capt. O. E. MICHAELIS,
Frankford Arsenal, Philadelphia:

My Dear Sir,—Your esteemed favor of the 29th of April has come to hand; and I will endeavor to answer your inquiries in a general way, and make such suggestions as may occur to me. Not having given the matter much serious thought, I fear that I shall not be able to render you much aid other than placing before you the facts which follow.

Our "open-hearth" furnaces, of which there are two, each having a nominal capacity of 30 tons, can melt without alteration from 37 to 40 tons each; thus enabling us to make a casting of from 75 to 80 tons (including sink-heads, sprues, etc.). At present, however, we are not able to handle with our cranes a casting or ingot requiring a hoisting force of more than 20 tons. Our pits (7 feet wide) are only 11 feet deep. They were made of this depth to enable us to cast large ingots for the hammer, which is capable of forging a 15-ton ingot. These pits might

be deepened to 20 feet without great trouble or expense, judging from the character of the soil at the present depth. This would permit the casting of guns of small calibre requiring a length of casting, including riser-head, of not more than 20 feet 6 inches, and of a weight not exceeding 20 tons. For larger castings a special pit and more powerful cranes would be necessary. Such a special pit, 20 feet in diameter, or less, could be sunk in front of the furnaces, on a line running midway between them. Two cranes (either hydraulic or steam), of a capacity of 120 tons each, would have to be erected on opposite sides of this pit.

As the bottom of the roof chord in our open-hearth plant is only 33 feet above the general level, a question rises as to whether or not this height is sufficient to allow the handling of the largest guns mentioned in your letter. If it is not, the roof would have to be raised to the height required to put in two 120-ton traveling cranes running on a track supported on columns. This would involve the removal of our present hydraulic cranes, and the substitution in their stead of two 10-ton traveling cranes, supported on the same posts or columns at a lower level. This would make the whole floor space available both for the casting of ordinary ingots and the casting of guns.

The changes necessary for casting will be slight, and consequently inexpensive. It is very difficult to estimate the cost of other changes. The pits, with jib cranes, would cost probably not less than $10 000; and the pit, with traveling cranes, not more than $150 000. Heavy trucks for transportation would also have to be provided, either by the company or by the Government. It is difficult, also, to make an estimate of the time that would be required to make these changes. Probably not less than 18 months would be required from the time when the plans were completed.

The price per pound of such work I could not estimate with my present limited knowledge as to what would be required by the Government in the way of a guarantee. In the event of failure, would the loss fall on the contractors?

In making the required changes we would be deprived of the use of our plant for quite a long time, and be obliged to give up a portion of our present business. What inducement would the Government offer us for giving up a profitable working plant, or changing it into an experimental one? In my judgment, until such time as the Government is willing to secure the contractor against possible loss, responsible par-

ties will not come forward and place their works and their capital at its service. I think that we possess greater facilities for such work than other establishments, and we would need to make fewer alterations and additions to our plant to enable us to turn out large guns than any other firm or corporation in this country. From our experience with smaller work, I am led to believe that larger castings for guns could be made with the regularity and of the solidity and strength required. Of course, some time might be required to develop fully this new feature in our business, to overcome the difficulties and risks attending the casting and handling of such large masses of steel, and to fulfill all the conditions required.

After casting the gun—following the Rodman system—I would recommend the following treatment: Place the casting, when cool, in an upright annealing furnace, and heat it evenly throughout to a cherry red. Then, in some convenient manner, cool the centre more rapidly than the outside. This, it seems to me, would give the interior compression and the exterior tension required, and the steel would be much more strong and ductile than if not annealed. We know that steel in an ingot or casting (without further manipulation) is comparatively weak, owing to the large size of its crystals and the consequent cleavage planes. By the process of annealing these crystals become much smaller and more intimately interlaced, which results in a great improvement in the mechanical properties of the metal; its tensile strength, limit of elasticity, and percentage of elongation and density all being greatly increased, as when the steel is forged. The fracture of a piece of steel after annealing (providing, of course, that it is solid) has every appearance of forged steel, and it is equally dense, if not more dense. In conclusion, I will say that I have no doubt that the Pennsylvania Steel Company would enter into any equitable arrangement with the Government whereby the desired results could be obtained. I would most certainly do all in my power to forward any and all experiments that the Department would undertake.

Yours truly,

L. S. Bent,

Superintendent.

The Pennsylvania Steel Company,
L. S. Bent, Superintendent.
Steelton, Penn'a, May 15, 1884.

Capt. O. E. Michaelis,
Frankford Arsenal, Philadelphia:

My Dear Sir,—Your esteemed favor of the 14th inst., with enclosures, has been received. To cast a 50-ton steel gun, I would not begin with less than 75 tons of ready metal. As to the cost, I have not any data by which I could approximate it; neither would I venture to undertake a gun of that size, even if all the mechanical conditions were equal to it, unless I could avail myself of the services of some party who had had experience in this pressure method. Otherwise I should want to begin with smaller guns, to find the precise conditions that the metal would take.

The actual cost of the metal—that is, when it was ready to run into the moulds—would be about 50 per cent. more than the cost of the iron used for gun metal; but there are so many conditions and contingencies involved in the work that it is very difficult to arrive at the probable cost. In the case of a possible mishap there would be on hand a large mass of steel which it would be next to impossible to get into such shape that it could be used. The risk incurred in handling steel is much greater than that of handling iron, as it chills so quickly; there must be no margin for doubt or uncertainty when you tap the metal; it will go somewhere, and if you do not provide a proper place to receive it, it will make an improper one without delay.

You have asked me to state a price on an article that I would not attempt to handle—purely from want of knowledge. If you could pay a visit to our works, in company with a person who has had experience in casting heavy ordnance, we could give you the benefit of our experience in handling steel, and you would gather many facts that would no doubt be of great assistance to you; but in depending upon me alone I fear that you might be led astray. Any information that I can impart I will most cheerfully give you, and will be at your service at any time you may choose to come to our works.

Yours truly,

L. S. Bent,

Superintendent.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

CCLXXXV.
(Vol. XIII.—August, 1884.)

LANDING ARRANGEMENTS FOR A CAR FERRY ON THE MISSISSIPPI RIVER.

By ROBERT MOORE, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, BUFFALO, N. Y., JUNE 10TH, 1884.

Ferries for the transfer of railroad cars across bays and rivers have become so common that they have hardly attracted the attention from engineers which their merits really deserve. For not only do they enable us to carry traffic without unloading where bridges are out of the question, but they do it so rapidly and cheaply that, even where there is no impossibility in the case, the building of a bridge is very often a matter of more than doubtful propriety, as involving a waste of capital. If the amount of traffic be not very large, or if speed be not the first requisite, it is often much cheaper to carry freight by ferry than by bridge, when the interest on the investment is taken into the account. Yet so greatly have engineers neglected works of this kind, that when I had occasion to construct one myself, I could find in print no plans or precedents whatever.*

* As illustrating the economy of this method of transfer as compared with a bridge, it may be worth while to note that at the ferry described in this paper, 300 cars can easily be transferred in 10 hours at a total cost not exceeding 25 cents per car. A bridge at this point would cost not less than $3 000 000, and might cost much more. Adopting the lowest estimate, and assuming further that 6 per cent. was paid for money, we should have an interest charge of nearly $500 per day, and the actual cost of transfer by bridge would be greater than by boat, until the traffic reached 2 000 cars per day, or about seven times the present traffic at this point.

Though, of course, all car ferries have many points in common, yet no two of them are quite alike, and nearly every one presents some original features. As a typical case, I have thought it worth while to give somewhat in detail the problems presented by the landing arrangements for such a ferry on the Mississippi River. The one which I shall describe was built by the writer in 1882, at the river terminus of the Belleville and Carondelet Railroad, opposite the southern limits of the city of St. Louis. As it has in use been thoroughly satisfactory and successful, it may be taken as a fair representative of the class to which it belongs.

The river at this point, and for half a mile up and down stream, is at present very nearly straight, with the thread of the current parallel to the banks and approximately in the centre. On the west, or Missouri shore, rock is found near the surface, within 200 or 300 feet of the water's edge, and the original shore line probably went back to the rock. But by means of cinders from the adjoining blast furnace and zinc works, and the deposit of sediment caused by the cinder piles, the shore line has been pushed out to its present position. The material used resists the action of water nearly as well as rock, and the shore is in a condition of great stability. Its elevation is above all but the greatest floods and its slope very steep.

The eastern, or Illinois shore, was, 30 years ago, about 2 600 feet distant from the present line of the western shore. But the Waterloo and Carondelet Turnpike and Ferry Company, whose road reaches the river at this point, in order to get a good landing for its boats, has, from year to year, in the season of low water, extended a rock dyke out into the river until it has now reached a point about 1 300 feet from the former shore line. The deposit of sediment which this work has caused, aided by the works of the East St. Louis and Carondelet Railroad above, and the Cairo and St. Louis Railroad below, has gradually brought out the whole shore line nearly to the end of the ferry dyke, until now the width of the river at mid stage is only 1 350 feet, or but little more than half what it was originally. During the six years from 1876 to 1882, the shore line was moved westwardly into the river 365 feet, or nearly 61 feet per annum. This is now the narrowest place in the river below the mouth of the Missouri, the width being 234 feet less than between the abutments of the St. Louis bridge, and the east shore is no less than 150 feet west of, or within, the line fixed upon by the United States engineers as the limit for permanent works. Owing to this contraction of the stream,

the current is very strong and the depth of water unusually great, varying in the channel (according to the reports of pilots) from 30 to 100 or more feet.

The land selected for the terminus of the Belleville and Carondelet Railroad, as shown on the accompanying Plate XXXIII, lies immediately south of the ferry dyke, and just north of the lands occupied by the Cairo and St. Louis (narrow gauge) Railroad. The tract owned by the railroad has a water frontage of 1 340 feet, and extends back from the river about 1 400 feet. It is all composed of river sediment, and, excepting a narrow strip on the east, is all the growth of the last thirty years. It is below the line of ordinary freshets, and, excepting the railroad embankment, is still overflowed once or twice every year. It was covered with a dense growth of willows, which assisted greatly in its formation, and which were afterwards utilized in protecting the front, as hereinafter described.

The vertical range of the river at St. Louis is $41\frac{4}{10}$ feet, the lowest water being that of December 21st, 1863, and the highest that of June 27th, 1844. Both these stages are, however, counted as exceptional, and are not taken as the standard for ordinary works. As the river has never come nearer than 4 feet to the extreme low water of 1863, except when closed with ice, it is safe to take this mark of 4 feet as low water for all purposes of navigation, and this is accordingly the "standard low water" of the United States engineers.

Reasoning in the same manner, the flood of 1844 is so far above all subsequent floods and all existing works that all the railroads on the east side of the river have adopted as the upper limits of their works standards from 4 to 6 feet below the high-water mark of 1844. A repetition of this flood would cut off all access to St. Louis from the east, except by boat, and submerge the town of East St. Louis from 7 to 9 feet deep.* Still it has been thought best to take this risk rather than to incur the great cost and inconvenience of the high embankments that would be necessary to avoid it. In the case of the Belleville and Carondelet Railroad, now under discussion, the standard chosen as the upper limit for construction was a line 18 inches above the flood of 1881,

* The tracks at the east end of the St. Louis bridge, at Relay Depot, over which pass all trains coming to St. Louis from the east, have an elevation of 3.7 feet below the flood mark of 1844.

which was the highest that had, up to that time, occurred since 1858, though it was no less than $7\frac{8}{10}$ feet lower than the great flood of 1844.

The two limits thus chosen gave a vertical range to be covered by the ferry incline of $31\frac{5}{10}$ feet. As the space available for the incline was limited, it was desirable to use as steep a grade as could be conveniently worked. By using such a grade, moreover, the length and weight of the moving cradle would be reduced, which is in practice a very considerable advantage. The grades in actual use on the Mississippi for ferry inclines vary from about $2\frac{5}{10}$ up to 5 feet per hundred. The grade chosen in the present case was 3.75 feet per 100, excepting the last 150 feet at the lower end, where it was increased to 6 feet. This change of grade was made in order to still further shorten the incline, and was admissible at the end, for the reason that this part would be occupied only by the cradle and never by a locomotive.

Owing to the changeable character of the river bank at this point, the problem of securing the best alignment and location for the incline was one of some difficulty. If put too far inland it might be silted up and become inaccessible in low water. This had actually happened at the terminus of the East St. Louis and Carondelet Railroad, about a quarter of a mile above. An incline constructed and used about twelve years ago has for several years been entirely buried, and is now, at low water, several hundred feet inland. On the other hand, to put it far out in the stream would be to invite destruction by ice gorges and floods. And here, again, the experience of our neighbors of the East St. Louis and Carondelet Railroad was of great value. The incline built to replace the buried one just mentioned was put out so far that hardly a year passes in which it is not disabled by driftwood or ice. Still another danger to be avoided is that of giving the incline too great an angle with the current; for in this case the boat in approaching the incline is brought so hard against the fender piles that its management is attended with much difficulty and some danger. The angle adopted in the present case was 18½ degrees, which has given perfect satisfaction to the pilots, and the location with reference to the shore is such that at low water about two-thirds of the incline is on land and one-third in the water. And so far there has been no trouble from silting up, and none from driftwood or ice.

As regards materials, the lower end of the incline was an ordinary pile trestle with bents (of four piles each) 15 feet apart, and offering

PLATE XXXIII
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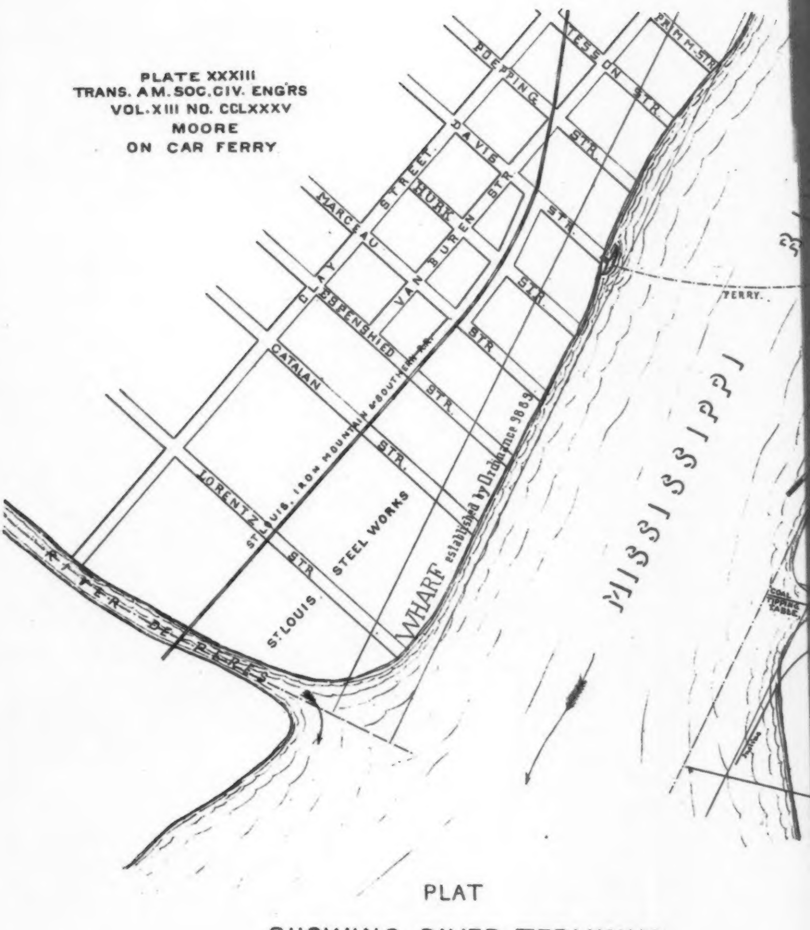
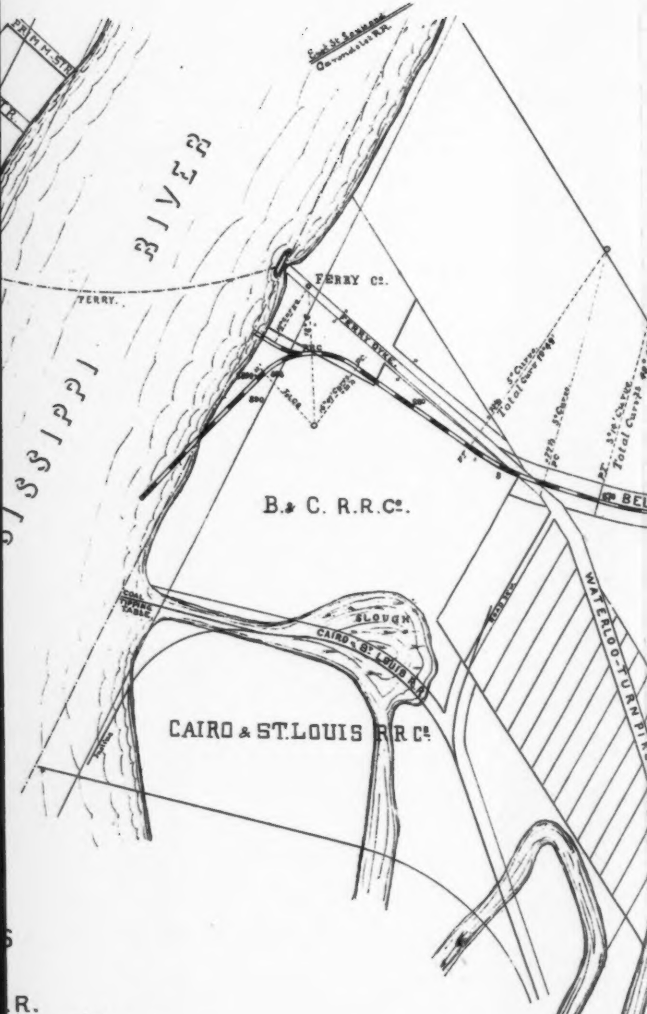
MOORE
ON CAR FERRY



PLAT
SHOWING RIVER TERMINUS
OF
BELLEVILLE & CARONDELET R.R.

SCALE 800 FT. PER INCH

Robt. W...
Ch...



R.

Robt. Moore
Chf. Engr.

BELLEVILLE AND CARONDELET R.R.
Total Curves
PRAIRIE DU PONT CREEK
ERLOO-TURNPIKE
850

no features worthy of special remark. The piles were carried back on to the land about 100 feet so as to guard against danger from undercutting. The upper end of the incline was a bank of sand ranging in height from nothing up to 7 feet. The only difficulties of construction were at the lower end, where for ten or twelve bents the piles had to be cut off and capped, and the stringers then placed in position under water. To do this the piles were cut off by a circular saw rigged on the same boat which carried the pile driver. The caps of green oak were then placed on the piles, held in position from the boat, and then secured by drift bolts which were driven by a 1-inch iron rod 10 or 12 feet long, working through a gas-pipe. This pipe was placed over the drift bolt and the rod then used as a hammer. The stringers, ties and rails which were to be placed under water were first framed and bolted together out of the water on the upper part of the trestle. The whole frame-work was then pushed forward into the water until it was directly over the bents on which it was to rest, loaded, sunk and secured by drift bolting in the manner already indicated.

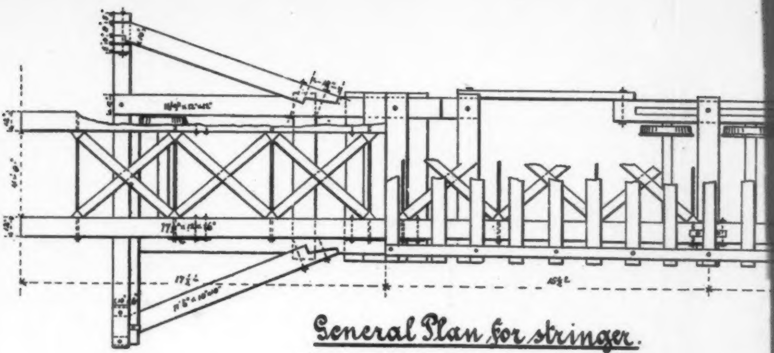
The chief problem in the case was not one of construction, but of maintenance. Owing to the extreme narrowness of the river at this point, the force of the current in floods and the consequent scour are very great. This was very clearly demonstrated during the progress of this very work. During a season of low water in February, 1882, the pile driving was begun and nearly completed, when an almost unexampled freshet suspended the work, and the water remained so high that work was not resumed until the September following. At the end of this time it was found that nearly all the piles driven for the incline, as well as those for a coal dump, a short distance above, had disappeared. In all, 200 piles had gone out, and soundings showed that over a large part of the ground occupied by the incline, the bottom was about 10 feet below where it was in February before.

The means adopted to guard against a repetition of this experience were substantially the same as those employed for similar purposes by the United States engineers in their works of river improvement on the Mississippi and Missouri, viz.: to cover the ground exposed to scour with willow mattresses and stone. These were made in the usual manner, by laying willow brush crosswise until they reached a thickness of about 12 inches, and binding them strongly together with wire. They were put together on inclined ways on the shore, pushed into the water,

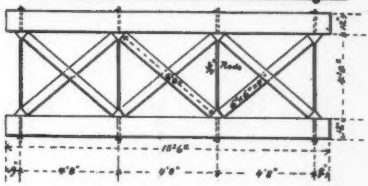
floated into place and sunk with stone. In size they were made about 40 feet square. Mattresses of this kind were placed along each side of the incline, with smaller ones between the bents, so as to cover the entire surface. The whole was then well covered with stone, which was placed with special care around the piles. In addition to this, the shore above the incline for about 800 feet, and about 150 feet below it, was also protected. This was done by sinking a line of mattresses below low water along the whole front, and covering the bank above the water with a revetment of brush and stone, after first grading it down to a slope of about 1½ to 1. The upper end of the incline, built of sand, was covered with a close pavement of stone, set by hand.

During the next summer (that of 1883), there was a freshet a foot and two-tenths above that of 1881, which put the sufficiency of this protection to a very thorough test. No weakness was developed, except at the outer edge of the mattresses along shore above the incline, where a scour of 2 or 3 feet had taken place. The revetment of the bank above the incline was also slightly damaged in a few places; but the incline itself suffered no damage whatever, although that of the East St. Louis and Carondelet Railroad, less than half a mile above, was so injured as to be useless for six or eight weeks, during which it had to be in large part rebuilt. Since this freshet the bank revetment has been repaired, and another line of mattresses has been laid outside of the first row, and the protection works are now believed to be sufficient.

The "cradle" or moving table, by which cars are transferred from the boat to the incline, was made in its general features like those in use at other landings near by, but with a fresh study of the details. Its height and consequent length were determined by the transfer boats of the Missouri Pacific Railroad, which were to use it. The details are shown in the accompanying drawing, Plate XXXIV. In use it has been very satisfactory, having both the strength and the flexibility which the circumstances of the case require. I have had occasion to make several copies of the drawing for use by others, though for other locations and different boats, no doubt, many changes in detail ought to be made. The plan is not offered as a model for other places, but simply as an example of a structure which has fulfilled its purpose, and stood the test of experience.



General Plan for stringer.



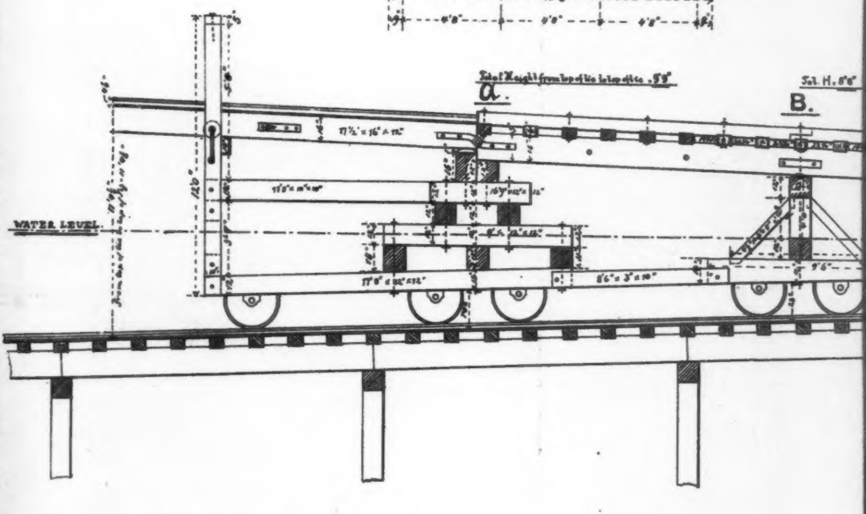


PLATE XXXIV
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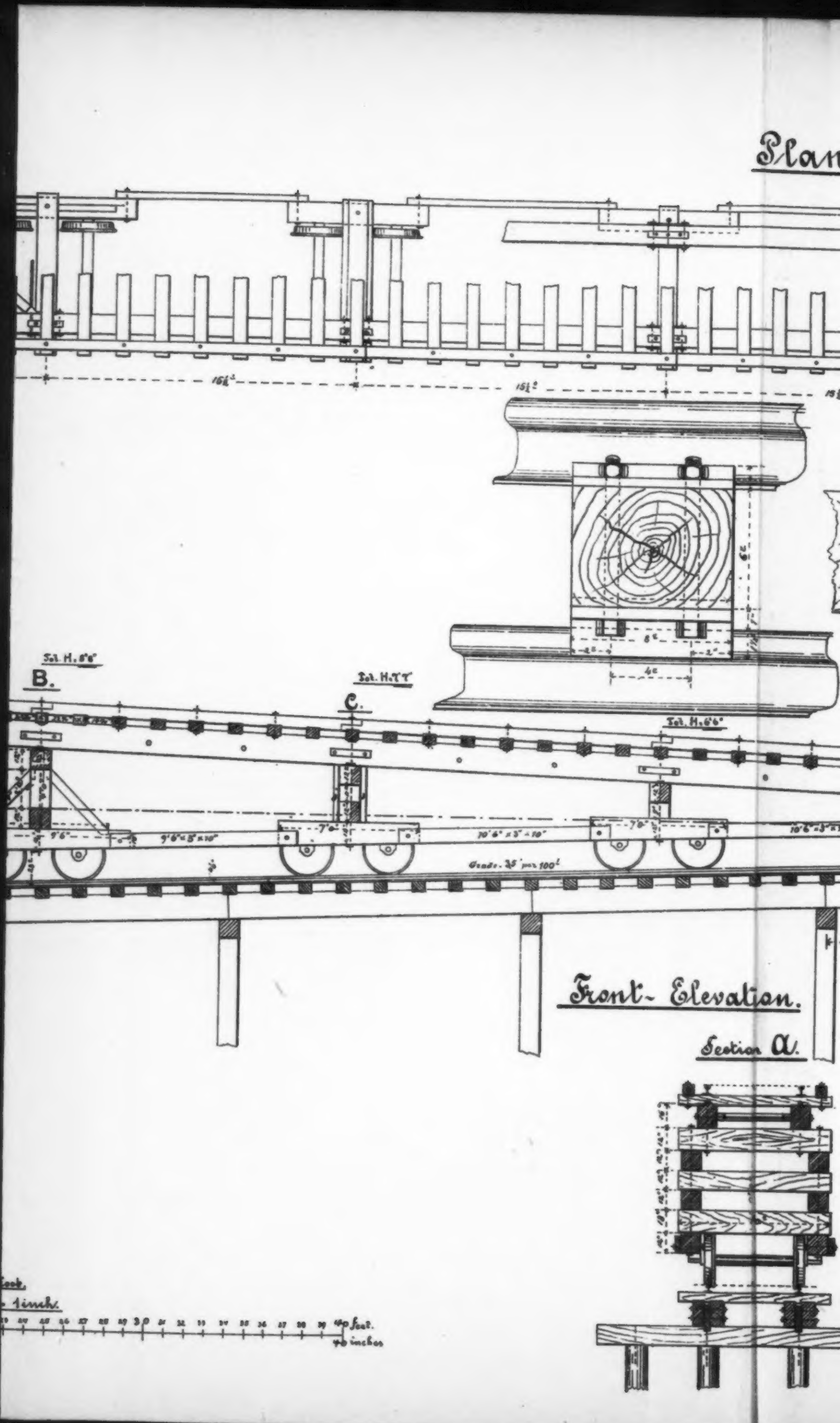
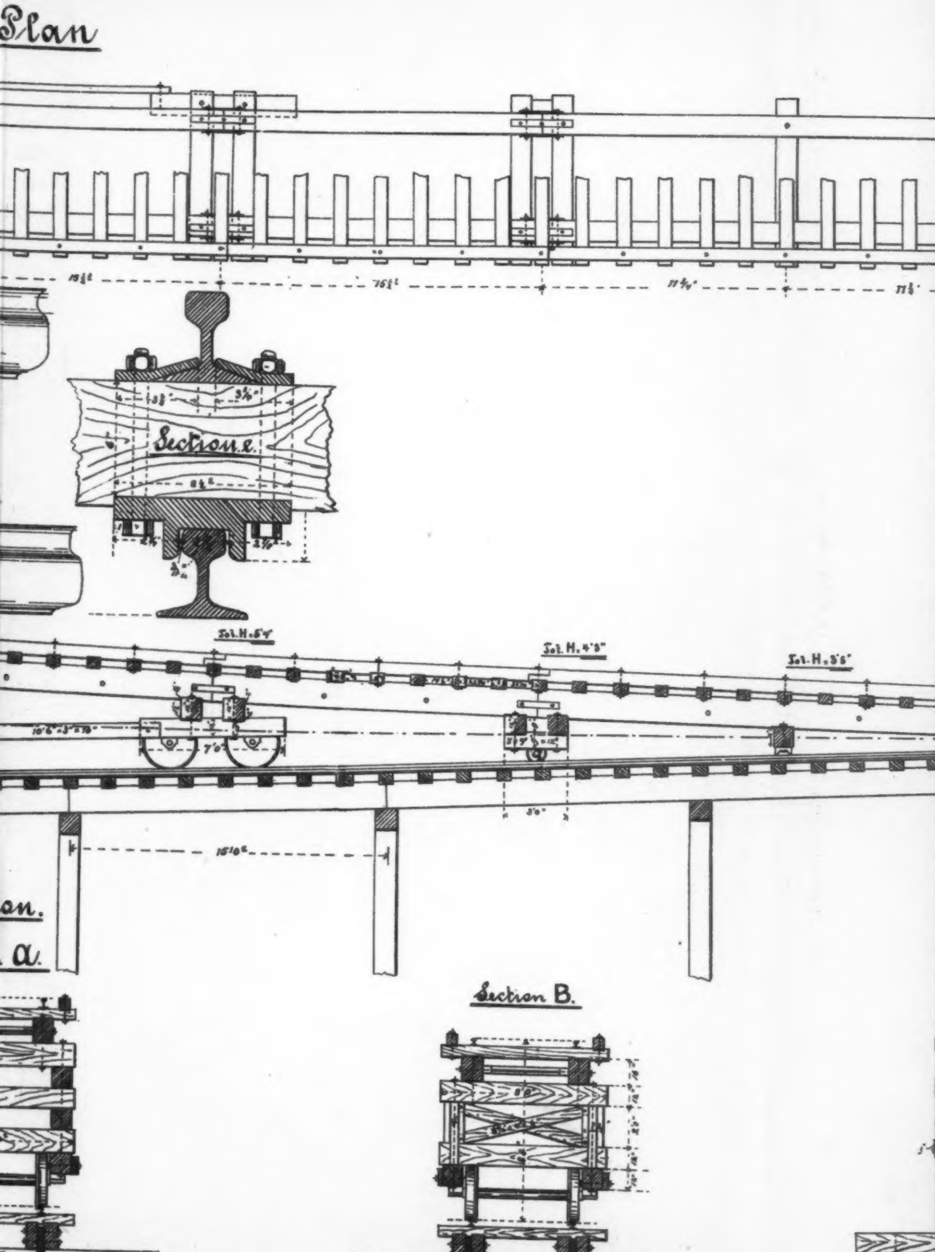
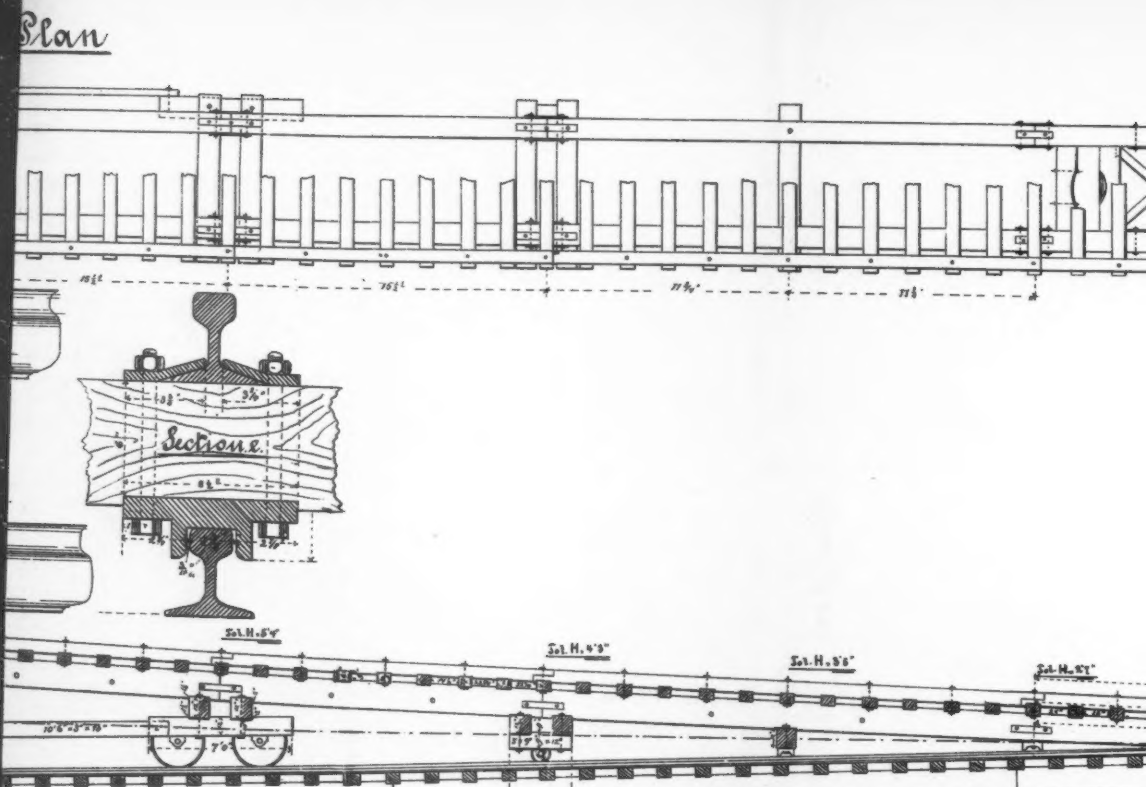
MOORE
ON CAR FERRY

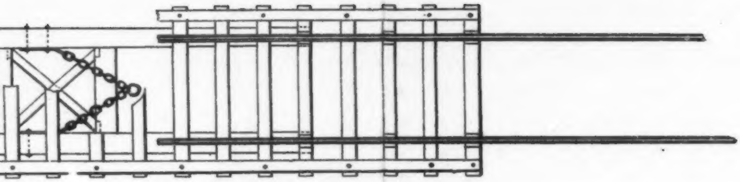
Scale 1/8 inch = 1 foot.
For the details 1/8 inch = 1 inch.



Plan
B.
C.
Front- Elevation.
Section A.


Plan
Section e.
Section B.
15'10"


Plan
Section E.
Section B.
Section C.
15'0"
7'0"
3'0"



Belleville and Carondelet Railroad.

ROBT. MOORE. Chf. Eng.

ST. LOUIS MO. 1883.